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ABSTRACT

The purposes of this volume are to report a survey of current practice in the construction and use of mathematical models for the education sector: to identify the most important technical and substantive problems confronting the model-building effort; and to bridge the gap between the advancing research pursuit of model-building and the lagging practical application of these models applied among the Member countries of the OECD. In 122 cases, detailed interviews, based on a comprehensive questionnaire, obtained information which was then analysed in terms of a classificatory framework. Next, a detailed and substantive description of the different models identified the significant technical and substantive problems encountered in applying the models to education, demonstrating the way in which these problems have been treated. Finally, the study poses the question of whether the models have proved useful in formulating and solving problems of educational policy. The analysis in the report is based on a set of annexes, published separately, consisting of the responses to the questionnaire and other supporting documents. (Author/KSM)

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MATHEMATICAL MODELS FOR THE EDUCATION SECTOR

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MATHEMATICAL MODELS FOR THE EDUCATION SECTOR

A SURVEY

LES MODÈLES MATHÉMATIQUES DU SECTEUR ENSEIGNEMENT

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PREFACE

The logic and tools of mathematics have proved exceedingly useful in helping to understand the physical phenomena around us. The relevance of these approaches for tackling the problems of individual and social behaviour is, however, disputable. Nevertheless, social sciences have come to rely on mathematics to an increasing extent in recent years. In the case of theoretical and applied economics we have a long experience in the use of mathematical methods but for social phenomena, other than economics, the use of mathematics has been of a relatively recent origin. This text attempts to document the application of mathematical models applied to the education sector in a large number of cases among the Member countries of the OECD. In each case a detailed interview, based on a comprehensive questionnaire, was carried out with the person concerned with the construction of a particular mathematical model. Information thus obtained from 122 respondents was then analysed in terms of a classificatory framework. This provided an aggregate view of the study of the art of constructing and applying mathematical models to the education sector. The next step entailed a detailed and substantive decription of the main and general features of different mathematical models used in education. The purpose of the description was to identify significant technical and substantive problems encountered in applying mathematical models to education and to demonstrate the way in which these problems have been treated. Finally, the study involved an examination of mathematical models designed for the education sector. The main question posed here is whether the mathematical models have proved useful in formulating and solving some of the problems of educational policy.

The analysis contained in this report is based on a vast body of information which has been summarised in a set of annexes. The annexes, referred to in the text, will be published separately.

They have been designed to serve as reference material for investigators in this field. The annexes are based on two kinds of supporting material:

a) the responses to the questionnaire;
b) supporting documents and other material concerning the mathematical model-building effort in education.

This material provides a unique collection of information which could be further explored for a deeper understanding of the nature and role of mathematical models for the education sector.

The current survey is a result of a collective project carried out by a team of investigators under the direction of Dr. Abdul G. Khan, in close collaboration with Dr. Paul M. LeVasseur, who are responsible for the co-authorship of the present text. A number of individuals made major contributions in the preparation of different parts of the survey and worked as members of the team during the survey or during the period in which the results were being analysed. They are: Timothy Marshall, Ruth Rose Parker, Constantine Soumelis, Philippe Michel Vallin and James Alexander Veech. In addition, Margaret E. Goldstone contributed to the final phases in the preparation of the report.

Chapter I

INTRODUCTION

1. PURPOSE

The purpose of this volume is to report a survey of current practice in the construction and use of mathematical models for the education sector. The analysis stands in between an in-depth investigation of specific mathematical models and a straightforward bibliography of the current effort in the field. But for those interested in the detailed functioning of the models we have tried to select a few models to expose their inner workings. And for others, who wish to have a reference volume on current research, we have provided a network of annexes to be used for this purpose. The main body, however, constitutes an aggregate analysis of a large number of mathematical models which, through a classification system, reveals the anatomy of the current research effort in this field.

The second, but no less important, purpose is to identify the most important technical and substantive problems confronting the model-building effort in education. Such information should encourage researchers to cross-fertilise their ideas with those of others working in the same area. The need for information exchange and dissemination, particularly at an international level, has been strongly felt by those who are currently engaged not only in the construction of models of education but also in their most effective use (suggestions concerning this are given in the concluding chapter). A number of worthwhile national and individual efforts have been taking place in isolation without the benefit of an exchange of information with similar work elsewhere. This report, therefore, provides a cross-sectional view from which specific selected information of special interest can be obtained.

In addition to this there is the third purpose of the report. We have reflected on the important issue of bridging the growing gap between the advancing research pursuit of model-building on the one hand and the lagging practical application of these models in the formulation of educational policies and the design of educational systems on the other. This has not been an easy question to tackle partly because empirical and computable mathematical models provide only one of the many informational inputs to the decision-maker. No one can suggest that decision-making in education, as well as for all human phenomena, can be sufficiently automated through models to become a substitute for sound judgement. But anything that will assist the process of making judgement should be strengthened and made more effective. It is hoped that this survey report could furnish information of relevance to assist the process of policy-making and decision-making in education.

Mandate and Background

Some of these considerations led the Secretariat of the OECD during early 1968 to formulate tentative proposals concerning the Organisation's future work on the development of mathematical models for the education sector. These proposals were discussed at length by the responsible committees and groups within the Organisation. The outcome of the deliberations was a mandate from the Committee for Scientific and Technical Personnel (since renamed the Education Committee) to conduct a survey of current educational model-building in Member countries as a prerequisite to deciding the future directions of work by the OECD in this field.

In response to this mandate, a detailed survey of the state of the art concerning educational model-building was carried out. The aims of the survey were as follows:

1. to investigate the general characteristics of the current model-building effort, its nature and scope in different countries, and the various approaches that have been adopted;
2. to bring out the significant technical problems of the models used in resolving these problems, both with regard to the problems of statistical estimation of relationships and their manipulation to yield meaningful results;

3. to provide insights into how the models can best be used in educational planning and decision-making;
4. to generate material for use in formulating guidelines for the direction of current and future work on educational model-building by the Organisation.

To facilitate the investigation, a substantial questionnaire was designed which, in almost all cases, was filled out by the interviewers. A special team was assembled and briefed on the use of the questionnaire before being sent out to implement it. In this way the Secretariat was able to gather a mass of information which was processed and analysed both manually and with the aid of a computer. This report provides the main findings of the survey.

2. BACKGROUND

The need for such stock-taking was timely for several reasons. The statement of these reasons will serve as a background to a discussion of the scope of the survey and its analytic usefulness.

The governments, with their swelling fiscal budgets for education, were under pressure to justify the vast outlays in view of the alternative claims of other public sectors such as health, transportation and, latterly, environment and ecology. Within the education sector itself the component that has grown fastest, claiming the largest share of the resources, has been higher education. The ever-rising trend in enrolments in both universities and other institutions of higher education turned out to be the single most important concern of several countries. This was also reflected in the model-building effort documented in the report. A very large number of models have been constructed, or are being constructed, to forecast student numbers in higher education, and in cases where it has been possible, to spell out the cost considerations and expenditure requirements of this "explosion".

To meet the twin challenge of growing demand for education and the financial constraints on expenditures there arose a need, not only to justify expenditures, but to bring about greater efficiency in the use of resources in all areas of education. Could quantitative and mathematical models give assistance in this respect in the face of a general scepticism concerning their utility for policy-making? In spite of the relative infancy of the model-building effort in education, the question was not unfair since the OECD was, to an extent, instrumental in promoting the so-called "human investment revolution". But like most premature revolutions this one also was starting to dissipate without tangible benefits for practical policies in education. There was need, therefore, to seek new directions of thought.

Secondly, the survey was a logical outcome of a series of steps taken by the OECD within its programme of work on statistical and quantitative analyses of education. In recent years OECD has convened four meetings of experts, all of whom were concerned in one way or another with the use of mathematical models in education.

The first of this series of meetings was held in March 1966 to explore the reliability and efficacy of mathematical models as a basis for educational planning. The six contributions reflected current practice in this field (Mathematical Models in Educational Planning, OECD, Paris 1967). At the second meeting, held in January 1967, the mathematical models discussed were even more specific since the contributions reported examples of the application of management techniques to educational administration at the level of individual institutions for local school systems (Efficiency in Resource Utilisation in Education, OECD, Paris, 1969). At the end of the meeting Professor Russell L. Ackoff, summarising the proceedings, warned that too many scarce research resources were being expended on tactical problems of education and too little on the strategic problems. He proposed that the primary concern should be with problems and not with the techniques and tools of research. A third meeting was convened in April 1968 to discuss programme marketing in education (Budgeting, Programme Analysis and Cost-Effectiveness in Educational Planning, OECD, Paris, 1968). Here the main focus of the various contributions was on the specific approaches of programme budgeting and cost-effectiveness. Participants described their research efforts both on the correct identification of costs and the economic evaluation of benefits. The final meeting, held in April 1969, was concerned with the problem of the management of universities in view of the fact that universities have become increasing consumers of scarce resources and, at the same time, ill-equipped to make an efficient utilisation of the available resources. University-wide management models developed in

North America and in Europe were presented and discussed at this meeting, providing the Organisation with an impetus for the launching of a major research and development programme in this area in the CERI.

Concurrently with the meetings, the Secretariat of the Organisation compiled a selected, annotated bibliography on (Systems Analysis for Educational Planning, OECD, Paris, 1969). This document includes a wide array of books, articles, papers and mimeographed documents available as of Spring 1968. The coverage of the material is far more extensive than is indicated by the title. Also, using illustrative data from France, the Secretariat staff was able to construct a large-scale computable model which related the education sector to the labour and production sectors of the economy in terms of a series of input/output relations. The purpose of this exercise was to demonstrate how decisions made for one of the three sectors - education, manpower and the economy - affect the requirements in the other two sectors. The model was used for a man-machine simulation at training seminars for national educational administrators held in 1967 in Dublin and 1968 in Paris. Finally, a detailed computer simulation model of the educational sector was constructed for use as a tool by policy-makers. The model permits an examination of a number of policy options in terms of future consequences and the dynamics of changes as a result of a number of quantifiably defined conditions affecting the educational system. Both these models have been covered in this survey. In the light of these forays, and with the aid of a network of contacts developed with research workers in the field, it seemed reasonable that OECD review the work on model-building carried out, not only in-house but in all the Member countries, before initiating new programmes in this direction.

The timeliness of the survey can also be attributed to yet another reason. Outside of the interests of the Organisation, the youthful discipline of the economics of education has been steadily evolving towards more and more sophisticated approaches to national educational matters. These models and approaches go far beyond the initial controversy between the manpower planners on the one hand and the rate-of-returners on the other. This evolution in thinking has been handsomely represented in the sequence of two volumes of writings on Economics of Education edited by M. Blaug (Penguin Books, 1968 and 1969). The Parnes-Tinbergen model of manpower planning, targeted to the less developed Mediterranean countries, was based on heroic simplifications about the way in which education was constituted in relation to the rest of the economy. These models assume highly inflexible demand structures associated with given levels of national income and use this assumption to carry out detailed projections of past trends without incorporating any considerations of cost effectiveness. On the other side, the Schultz-Dennison model, inspired by the investment theory of economics, used the concept of human capital formation and its economic evaluation. But this raised extremely difficult, if not fatal, problems of both an empirical and a theoretical nature. The fundamental empirical question arose from attempts to identify and measure the increase in earnings that are associated with education, without taking into consideration differences in innate abilities, race, employment, location, family background, etc. Similarly, Dennison's calculation that 42 per cent of the growth in per capita and national income in the United States over the period 1929-1959 can be attributed to education is fictitious, since we are unable to isolate the influence of education from other influences on the national output in any meaningful way. Nor did it appear necessary or sufficient to consider education as a collective consumer good without reference to its contribution to future individual and national productivity. Clearly, the motivations to receive formal schooling spring from a number of sources such as parental influence, search for knowledge, perpetuation of a non-adult non-working life, in addition to the calculations of future earnings.

Be that as it may, these theories and approaches yielded a great deal of insight and, sometimes, provoked heated controversy. But in several places researchers had already moved ahead into a detailed examination of the structure of education, at least in its formal aspects, and the underlying behavioural assumptions regarding its entities. In so doing they were relying more and more on the use of mathematical and statistical models as aids to their analysis. A survey was therefore needed to cover this ongoing research and point out the main characteristics of the current effort, the significant problems encountered and the methods used for resolving them.

3. COVERAGE

Models Covered

The questionnaire survey, which forms the information base for this report, was conducted in practically all the countries of the OECD (Finland had joined the Organisation only recently and could not be included because of insufficient information on the subject). In each of these countries the coverage was restricted to current work in model-building. As a result, information was collected on work on those models that were in progress, or had recently been completed, or were definitely planned for the near future. As many as 54 out of the 122 models were described as "in progress" (only 4 models were still in a planning stage). Work on the remainder was considered as finished, even though in a number of cases revisions and updating were either being carried out or were planned for the future.

The research strategy for information collection of interviewing those actively engaged in model construction was a matter of deliberate choice. It facilitated the preparation of the report on current effort in the field which could not have been possible had we relied solely on library research to extract the desired information. But this meant that significant, but not so recent, efforts in model-building which could not be tracked down in our direct interview method could not be covered by the survey.

As regards the coverage of the current effort itself, while the Secretariat staff were suited to secure information on this work in Member countries, it was not possible to make the coverage as complete as would have been desirable. In the light of the Secretariat's work in the field described above, a network of contacts had already been developed to facilitate the survey. Nevertheless, it is our guess that we may have failed to contact a number of individuals and non-officials engaged in educational model-building. Given the limitations of time and resources this gap in the survey was inevitable.

As regards the geographic coverage of the Member countries, we were in a fairly good position in Western Europe, and particularly in those countries that could be described as "model-rich". Our coverage of North America, and particularly the United States, was somewhat weakened by the distances and diversity in these countries. In any case there was a lesser degree of official and unofficial interest, particularly in the United

States, on overall educational planning models. We have reason to believe that model-building efforts in Japan were well represented since the questionnaire survey was carried out on our behalf by a local institute.

There are only a few Member countries where we failed to find any reportable model of education. But, as expected, the distribution by country location is quite uneven. More than a dozen models for each country were canvassed in the United States, Canada, the United Kingdom and the Federal Republic of Germany. The next group of countries with at least half a dozen models included Belgium, France, Ireland, Japan, the Netherlands and Norway. The rest of the Member countries have fewer models and in some of them we were unable to find any explicit model of the education system. Furthermore, we have also included in our stockpile of models three that have been constructed within the international organisations (including the recent work of the Secretariat).

The model count itself is no indication of the magnitude or the quality of the effort. Large-scale models comprising a number of component sub-models certainly represent a greater quantitative and qualitative effort than a simplified single exercise in establishing a relationship between a set of variables. Therefore, the head-counts should at best be regarded as reference information for making a systematic investigation of the direction and nature of effort in each of the countries.

Models not Covered

As a matter of deliberate choice the survey does not include models concerned with certain specific fields. These exclusions were due to the fact that the interest of the survey was largely concentrated on macro models and models concerned with the major sub-sectors of education. The first category of models not covered comprise those models that were designed for the planning and management of individual institutions such as universities. We were aware of the fact that a great deal of model-building effort in the field of education is being carried out at an institutional level, particularly in North America. Nevertheless, a substantial number of generalised models of institutions has found its way into the survey. These institutional models should be regarded as illustrative and not representative. In the second place, general manpower planning and manpower forecasting models had to be excluded. However, we have included those manpower models which (a) identify specific links of manpower with the education system and (b) express a demand for qualified manpower in terms of the need for graduates of specific educational attainment levels. The third type of models which fell outside the scope of the survey was the learning model which investigated the cognitive and non-cognitive (e.g. emotional development) processes of individuals and groups and which evaluated pedagogical strategies.

4. THE QUESTIONNAIRE

The questionnaire was specifically designed to facilitate this investigation and to systematise the collection of relevant information on mathematical models of education. It was quite comprehensive in scope and represented a tour de force. The questionnaire was used essentially by field investigators who were briefed in advance on the scheduled interviews. Because of the variation of the respondents, the interviewers were expected to exercise considerable judgement in the use of the questionnaire. It was designed to serve as a "programmed" check-list which followed a logical sequence of questioning. The interviewers were later able to edit the replies they had received.

The relevant questions in the questionnaire were coded so that the responses could be computerised for retrieval and processing. This facilitated not only the subsequent listing of the material but also the preparation of a number of cross-tabulations which could be analysed in the aggregate. Altogether there were more than 100 questions. These could be grouped under ten broad headings (of course, only parts of the questionnaire were relevant in each case depending on the nature of the model-building effort).

1. Questions on the type and structure of the model; variables and equations included; time horizon.
2. Questions on types and shapes of equations and solution procedures.
3. Questions on mathematical programming models.
4. Questions on parameter estimation techniques used.
5. Questions on special features of the model and the use of the results.

6. Questions not covered by explicit models concerning student projections, teacher demand and supply projections, cost and other resource projections.
7. Questions on the position of the working unit in the governmental organisation.
8. Questions on the relationships of the working unit with other organisations and control of joint projects.
9. Questions on the financing of the projects of non-governmental organisations.
10. Questions on external responsibility of unit; internal structure, functions, organisation and training.

To illustrate the logical sequence of the type of questions we have shown a summary chart of the flow diagram of the questionnaire (Figure I.1). The questionnaire itself is included in Annex 5 together with a detailed flow diagram.

This questionnaire survey of model-building in education is probably the first of its kind. We were aware of a number of international surveys of model-building in the area of economics and we have drawn upon the experience of these by contacting the individuals responsible for these surveys. But the initial reconnaissance revealed to us the need for a specially tailored questionnaire to suit the particular problems involved in model-building for education. When, and if, a follow-up survey is carried out, it will be possible to use a significantly truncated version of this questionnaire in order that the information contained in this report can be updated relatively quickly and economically.

5. OUTLINE

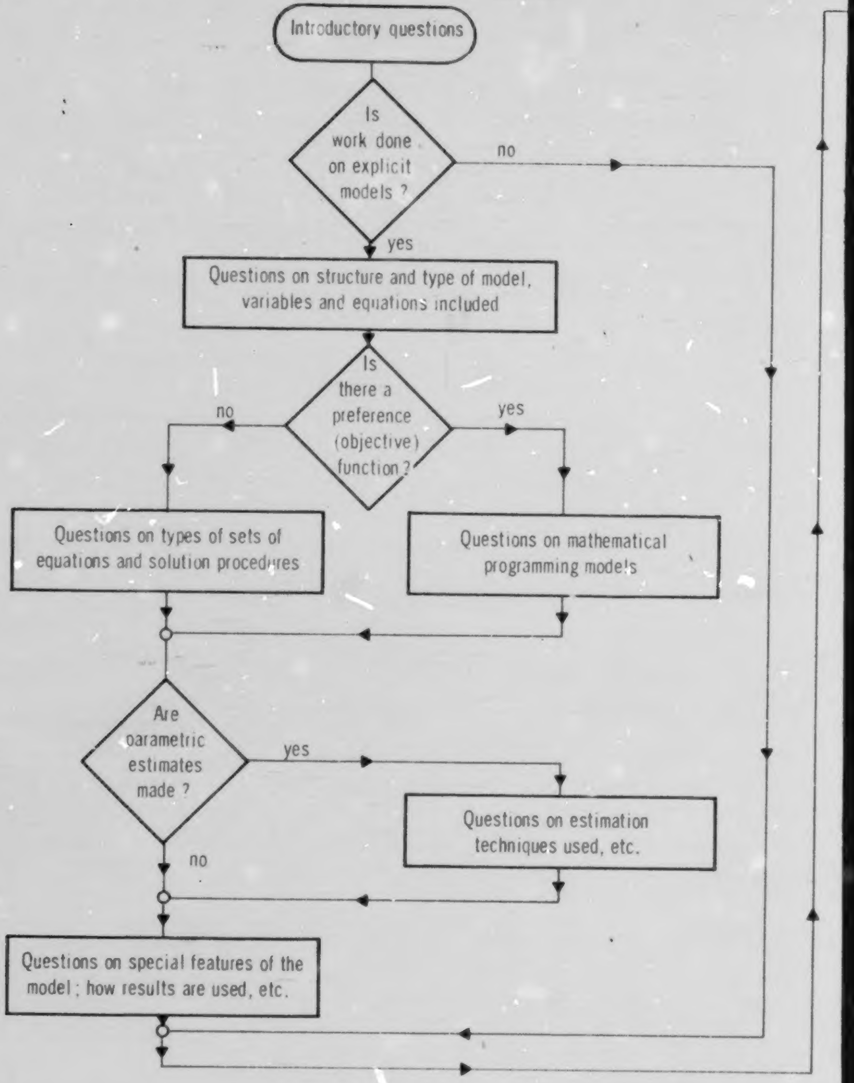
With this background we will now give a sketch of the outline of this report. The report describes the nature of the survey of models in education, the main characteristics of the model-building effort and an analysis of the wealth of material collected which in itself will be of use and interest to different people. The report draws upon 122 questionnaire responses obtained by the interviewers who canvassed all the educational model-building efforts that were known to the Secretariat at the time the survey was conducted. It is divided into three more or less self-contained parts.

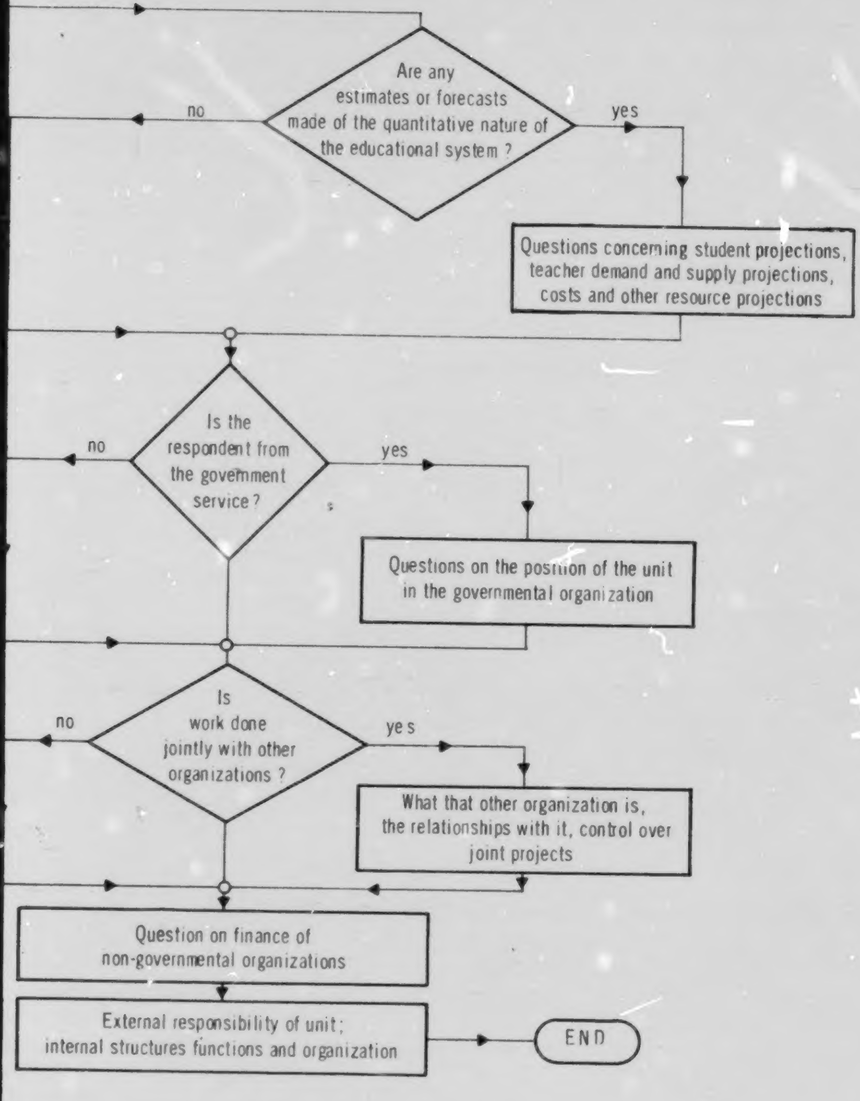
The first part describes, in general, the nature and role of mathematical models in education. Our main problem here is to elucidate the concepts (Chapter II) in order to draw up a classificatory framework (Chapter III) which could be used to illustrate the basic characteristics of models and analyse them in the aggregate (Chapter IV). When the material being examined is of a heterogeneous character, it becomes necessary to employ some kind of classification which can then be used as a reference for the analysis. Bearing this in mind, we have attempted to develop a classification system of the large number of models canvassed, the problems to which they were directed and the analytic techniques used to obtain solutions. We hope that this classification system can be useful even outside the scope of the survey reported here. In any case, this methodological initiative has proved particularly useful for the ordering of the data and the analysis of the material on models of education available in the responses to the specially-designed questionnaire.

The second part of the report gives a substantive description of the mathematical models in terms both of their subject matter (Chapter V) and the techniques used (Chapter VI). The art of model-building, in the social sciences at least, is such that matters of substance can not be completely divorced from the techniques employed. For example, the use of transition matrices to describe education is intimately related to our conception of the structure of the education system in terms of the flow of students through various channels and from one level to another. Also, the demand functions for education follow the traditional econometric practice of using multiple regression analysis. Therefore, whenever it has appeared suitable we have shown the interplay of the subject matter with the technique or techniques employed. But we have not attempted to provide the material in the form of a manual or handbook that could be useful to practitioners of the art even though such an undertaking would have been quite useful. To illustrate the substance of the models it was necessary to select a few cases and examine them in detail (Chapter VII). The selection was deliberately biased in order to represent only large and complex models in order to demonstrate the way in which they have been constructed and are manipulable to provide potentially useful results.

The third part deals with the problems and purpose of mathematical models for the education sector. The problem of the education sector that concerns us here is the formulation of

Figure I.1. FLOW DIAGRAM OF QUESTIONNAIRE
(Summary Chart)

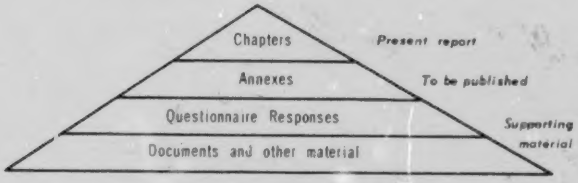

Introductory questions
Is work done on explicit models ?
no
yes
Questions on structure and type of model, variables and equations included
Is there a preference (objective) function ?
no
yes
Questions on types of sets of equations and solution procedures
Questions on mathematical programming models
Are parametric estimates made ?
yes
no
Questions on estimation techniques used, etc.
Questions on special features of the model; how results are used, etc.


Are any estimates or forecasts made of the quantitative nature of the educational system ?
no
yes
Questions concerning student projections, teacher demand and supply projections, costs and other resource projections
Is the respondent from the government service ?
no
yes
Questions on the position of the unit in the governmental organization
Is work done jointly with other organizations ?
no
yes
What that other organization is, the relationships with it, control over joint projects
Question on finance of non-governmental organizations
External responsibility of unit; internal structures functions and organization
END

public policies (Chapter VIII). It is important to make a distinction between the problem of system design and the problem of policy-formulation to attain specific targets. We shall try to judge the relevance of the models in terms of structural and policy decisions in the educational sector, bearing in mind that the structural goals and policy issues themselves are often ill-defined and that decisions must sometimes be motivated by reasons other than those that may appear rational in terms of a mathematical model (Chapter IX). The summary of findings and recommendations on the future work are given in the concluding chapter.

The reference material has been relegated to the annexes, to be published separately as an OECD document. The annexes have been set up to facilitate their use in tracking down specific information concerning the model-building effort surveyed. The material in the annexes is closely related to the statements in the chapters and, wherever possible, this has been cross-referenced(1). In addition, the annexes themselves are inter-related. The way of using the annexes will be spelt out at the beginning of that document. As far as possible the material provided in the annexes has been exhaustively drawn from the responses to the questionnaire. These responses, and the accompanying documentation, provide a far greater amount of information than could be incorporated in the annexes or even analysed within the limits of this report.

The information pyramid on which this report has been built is illustrated below. Only the top layer of the pyramid is contained in this volume, the second layer to be published at a later date. The questionnaire responses as well as the accompanying documents are available at the OECD.



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1) The numbers in brackets appearing in the present report refer to the model number used to identify each model in the annexes.

Part One

NATURE AND ROLE

Chapter II

CONCEPTS

1. GENERAL CONSIDERATIONS

Before elucidating the main concepts underlying the survey and the models surveyed, we shall make some general comments on the nature and role of mathematical models in education.

The main consideration to be borne in mind is that the methodology underlying the models in education is, to a large extent, derived from some of the fields of applied economics. There are three principal reasons for this. First, with the exception of economics, model-building is relatively undeveloped and untested in the study of social phenomena, notwithstanding the significant advances made in recent years. It is therefore necessary to look to the experience already available in building models of the economy or of its parts. Secondly, since some of the problems of the education sector involve the efficient use of scarce resources, it has been possible to claim a special field called the economics of education emphasizing the problem of economic evaluation of education. A prima facie case can be made for the application of the relevant quantitative techniques of economics to this specialised area, just as to any other specialised area of economics. Thirdly, at least one aspect of education has been compared to the production process of the economy studied with the aid of an input/output model developed by Wassily Leontief. Through a system of equations the production sectors of the economy are related to each other, since the output of a sector may be used as input by itself or in another sector, and the remainder being disposed as final use. In education, there are a number of levels, which could be regarded as analogous to the production sectors, through which the human entrants pass in order to receive the final qualification or to drop out of the process. These, therefore, are some of the reasons why it has been possible to transfer mathematical models from economics to education.

But the economist has no monopoly over the model-building effort in education. To a lesser extent such fields as sociology, psychology and demography have contributed to the art. This is as it should be, since the problems of the efficient use of resources can not exhaust all the aspects of the study of the education sector. In order that projections of demand for education can be made, the accurate evaluation of the trends in the birth-rate and the bulge resulting from the World War Two baby boom is not unimportant. The statistical and empirical work concerning the problems of equality of educational opportunity has drawn more upon the field of sociology than any other discipline. Economic theory too has provided an opportunity to test the hypothesis that the expected future stream of lifetime earnings governs the educational choice of individuals. It therefore appears that the analysis of the education sector may call for a genuinely multi-disciplinary attack, with the aid of mathematical models. But it is premature to say whether such a hope is on the verge of being realised in any effective way.

2. TAXONOMY

After the general remarks made above we can now turn to some taxonomic considerations. Because of the ambiguity of terminology it will be useful to provide a blueprint for the use of terms concerning mathematical models. This taxonomy should not be considered as definitive. Our purpose is more to elucidate the concepts in the context of their use rather than to provide statements of scientific precision. These will be workable definitions in two senses: first, the definitions have been used as a basis for carrying out the questionnaire survey of current work on mathematical models in education and, in the second sense, these definitions can become the basis for developing a classification system for the various mathematical models and their components.

In recent years a number of knowledge professions and knowledge fields have sprung up vying with each other for recognition and advancement. These are, for example, operations research, management science, systems theory, cybernetics, and control theory (and more recently "policy sciences"). There are no hard and fast distinctions between these various approaches. Differences in orientation, however, arise from historical and professional reasons as well as from differences in subject-matter emphasis. It is, however, safe to say that in most cases all these approaches rely on some kind of mathematical model-building effort as a basis for their investigations (with the probable exception of policy sciences). And the models, in turn, rely on some kind of an analytic-quantitative technique. The concept of the model and the associated techniques is, however, quite general.

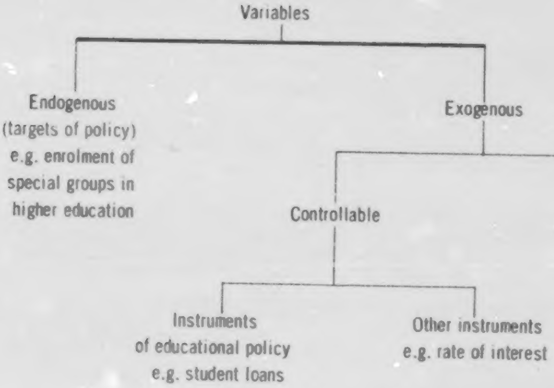
Because of the primitive as well as heterogeneous nature of the analytic-quantitative effort in education, it is perhaps not desirable to adopt a single definition of models. One way to handle this problem would be to make an initial distinction between explicit models and implicit models. Explicit models will, of course, cover all those conventional exercises in model-building which set up mathematical relationships between two or more variables. But by this definition we would have excluded any attempt to estimate, or forecast, the quantitative characteristics of the education system which does not rely on an explicit model. While the explicit model is an abstraction designed to study the quantitative interactions among the phenomena of education, implicit models may be regarded as judgmental quantitative estimates on forecasts of educational phenomena, the interactions among which are not specified in any formal sense. This latter type of work is by far more prevalent in the field of education and is in a more usable form than the conventional mathematical models of education. In actual situations of educational planning and forecasting it is more common to draw upon isolated estimates and forecasts of variables in order to come up with a more or less consistent set of numbers describing the future state. But underlying such an exercise one can claim that there is an implicit model. The implicit model may not appear as elegant as the explicitly-stated mathematical model; nor would it have the characteristic of demonstrable consistency among the various estimates used. The main concern of this report, however, is with the explicit models of education.

Therefore, the working definition of an explicit model has been taken as follows: a model of education is the representation, in mathematical terms, of the relationships linking two or more variables, at least one of which is related to the education sector. Armed with such a definition it is possible to set out a blueprint showing the various components which need to be incorporated for a full-fledged empirical model-building effort. There are four component parts of a full-fledged empirical model-building effort in education as in other fields concerned with social phenomena. These are:

a) variables describing the phenomena;
b) relationships among variables;
c) estimates of the parameters governing the relationships; and
d) the solution procedures for the model.

A variable is a mathematical expression that can take any value. Variables are often represented as symbols in an equation which could be replaced by numbers. Broadly speaking, we can divide the variables into two kinds: endogenous variables and exogenous variables. While the values of exogenous variables are given from outside the model, the values of the endogenous variables are obtained from the solution of the equations underlying the model. Therefore, we may say that the direction of causality in the model runs from exogenous variables to endogenous variables. The distinction rests upon how the variable is treated in the model and not on its intrinsic nature. For example, a model of primary education may consider the supply of teachers as given, and therefore exogenous, in order to calculate the available places in primary schools and thereby proceed to calculate the output of the primary education sector. On the other hand, a model of teacher demand and supply concerned with primary education will need to treat the availability of primary education teachers as an endogenous variable influenced by such factors as wage rates and other labour market considerations.

One way of looking at the exogenous variables is to regard them as either those that can be controlled by the decision-maker or those that cannot be controlled. Often the controllable exogenous variables can be used as instruments of educational or other policies to attain certain desired values of the endogenous variables. It is this direction of influence that is of interest in the use of mathematical models for policy and decision purposes.


Variables
Endogenous
(targets of policy)
e.g. enrolment of
special groups in
higher education
Exogenous
Controllable
Non-controllable
(data)
e.g. demographic
factors
Instruments
of educational policy
e.g. student loans
Other instruments
e.g. rate of interest

For the construction of models, it is not enough to list the variables. We also need to specify their relationships among those variables under consideration. These relationships are often written as equations, which are statements showing the equality of two expressions appearing on each side of the equation. It is possible to speak of different shapes of equations, for example whether they are linear or non-linear. But also we can look at the system of equations which comprise the models, to examine them as a whole. There are three non-mutally exclusive possibilities. The equations may be independent (one equation has no relationship to another), recursive (the solution of one equation depends only on the solution of another), simultaneous (where the equations are inter-related and the solution is to be obtained by their simultaneous manipulation). A multiple regression equation relating student achievements to their socio-economic background variables can be considered as an independent equation. An example of a recursive system would be if one equation were used to solve for the number of secondary school graduates and a second equation included this number to determine university enrolments. The two equations form a recursive system. A typical example of a simultaneous set of equations would be a demand and supply model of teachers where the demand and supply equations need to be simultaneously solved to obtain the values of prices and numbers.

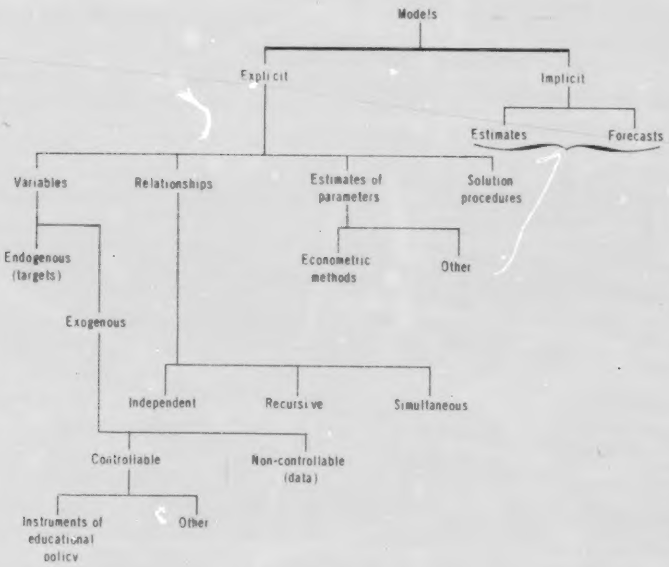
The third component of the model-building effort is the estimation of parameters. The parameters measure the intensity of relationships among the variables and there are a number of methods for estimating their values. The parameters are similar to exogenous variables in the sense that their values are determined from outside the model. They differ, however, in that they must be pre-assigned numerical values which have to be estimated in advance on the basis of additional sources of information. Much of the effort in the field of econometrics is devoted to the methods of estimating values of parameters, but it is also possible that the values of parameters can be estimated through expert judgement without reliance on statistical methods.

To complete the cycle of model-building effort we need to mention solution procedures. In order to obtain the values of endogenous variables, a model, or the system of equations underlying the model, needs to be solved. A certain class of models is those that have a unique solution. However, there is another class of models known as mathematical or linear programming models which adopt a somewhat different procedure. Because such models contain inequalities we consider a solution space rather than a solution point, which implies that there are an infinite number of solutions. Nevertheless, in order to obtain a unique solution it is possible to introduce some criterion function which will enable the procedure to choose from among others that solution which can be regarded as the best. Such optimisation procedures have also been used in the model-building effort in education.

As an obiter dictum we should also distinguish between deterministic and stochastic models. While the former attempt to explain the systematic variation of the expected values of the phenomena, the stochastic models attempt to explain the distribution and dispersion of this phenomena by introducing random elements into the model. Such probabilistic considerations become necessary if we assume that the relationships underlying the model are, to some extent, erratic. This does not mean that the nonstochastic models do not contain any stochastic considerations. To permit statistical inferences it is necessary to introduce disturbance terms (residual terms in a regression equation) into the estimation procedures. But this passive way of handling the problem cannot justify the model's being labelled as stochastic.

A crude taxonomic chart of the various elements of models is shown on Fig. II.1.

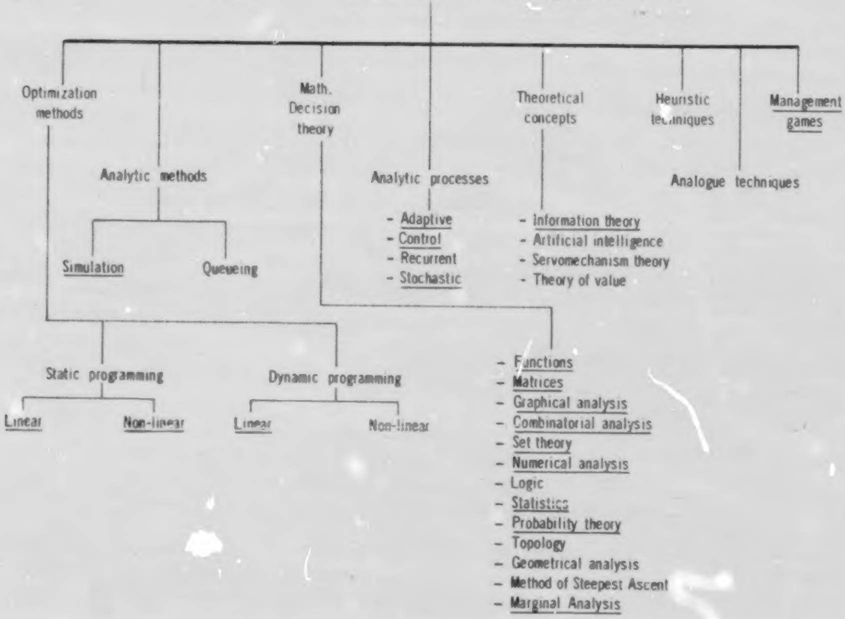
Figure II.1. CHART OF THE VARIOUS ELEMENTS OF MODELS


Models
Explicit
Implicit
Estimates
Forecasts
Variables
Relationships
Estimates of parameters
Solution procedures
Endogenous (targets)
Exogenous
Econometric methods
Other
Independent
Recursive
Simultaneous
Controllable
Non-controllable (data)
Instruments of educational policy
Other

3. TECHNIQUES

Having examined the taxonomy of the elements of the model-building effort, we can now turn to the distinction between the models themselves and the techniques used in the construction of models. Mathematical model-building represents a general approach to problem-solving. For this general approach to take a complete shape it is necessary to employ relevant techniques to those problems which are amenable to the use of the techniques. A detailed consideration of available techniques involved in the model-building effort is beyond the scope of this volume. Nevertheless, it will be useful to provide information on the availability of the wide array of techniques in at least one knowledge profession. For this purpose we have chosen the field of operations research. The reason for this choice is that the emphasis on techniques has been relatively greater in the field of operations research than in other related fields, such as management science or systems analysis. The practical areas of application of operations research techniques have been many. To mention only a few, there are science, government, military, general economics, industry, utilities, trade and service sectors (including education).

Figure II.2. PROBLEM-SOLVING TECHNIQUES OF O.R.


Optimization methods
Analytic methods
Math. Decision theory
Analytic processes
Theoretical concepts
Heuristic techniques
Management games
Analogue techniques
Simulation
Queueing
- Adaptive
- Control
- Recurrent
- Stochastic
- Information theory
- Artificial intelligence
- Servomechanism theory
- Theory of value
Static programming
Dynamic programming
Linear
Non-linear
Linear
Non-linear
- Functions
- Matrices
- Graphical analysis
- Combinatorial analysis
- Set theory
- Numerical analysis
- Logic
- Statistics
- Probability theory
- Topology
- Geometrical analysis
- Method of Steepest Ascent
- Marginal Analysis

Summarised from Operations Research 15 Year Index, ORSA, Baltimore, 1970.

Historically, the most extensive area of application of operations research techniques has been in military problems. Nevertheless, there has been increasing interest in the application in the service sectors of the economy. In the accompanying chart we have listed a large number of problem-solving techniques of operations research classified into eight major groups. Illustrations of these techniques can be found by reference to the source document.

It is not possible in this report to explain or illustrate the use of these techniques in general or in the field of education. Using our judgement and in a highly subjective way, those techniques that are directly relevant to model-building in education have been identified. There are altogether 30 or so techniques that can be distinguished from the chart (Figure II.2) which are grouped under eight headings. Of these 30 techniques there are 18 that can be considered as relevant to model-building in education and these have been underlined in the chart. The actual use of some of these techniques will become apparent in the relevant parts of this report where we discuss the models in detail.

Chapter III

CLASSIFICATION

1. PURPOSE AND STRUCTURE

Because of the wide differences in the nature and role of mathematical models in education, and also because of the wide array of techniques used in different ways as part of each model, it becomes necessary to draw up a detailed classification scheme that permits a large measure of comparability of the various elements of the models of education. A standard framework for inter-model comparisons requires that we distinguish those characteristics that are common to the different models covered by the survey. The basis for any classification system could be ascertained in either of the two ways: first, on a priori grounds it should be possible to determine those characteristics of models which could be used to set up a classificatory framework for inter-model comparisons; second, this could also be done empirically after an examination of the characteristics of the models, which could then be made to yield norms for comparison. Having lamented the lack of sound theory underlying the model-building effort in education, it appears that there is no alternative to the use of an empirical approach for setting up the classificatory framework. A careful examination of the large number of models from different viewpoints provided us with a body of information useful in determining the common features of the different models and thereby enabling us to draw up a comprehensive list of categories and elements comprising the classification system according to a number of characteristics.

The purpose of developing a detailed classification system is as follows: the classification system proposed here can be considered as a road-map. A road-map cannot contain all the details of the terrain but only those that are significant and relevant for the person planning the journey. Thus, the classification system will aid us in searching and examining those types and characteristics of models that are of particular interest. Further, the proposed classification system can provide insights into patterns discernible in the vast and disparate effort of model-building in education. A pattern will not be obvious without the use of a framework for ordering the various bits and pieces of work, as well as the larger-scale efforts, in model-building. Finally, the classification system, by charting out the territory in an exhaustive manner, can be used as an instrument in finding areas of strength and weakness concerning the effort as a whole. It may be possible to use this information in determining research priorities for future effort in this area.

The structure of the classification system can be elucidated using five terms describing the features of the models: characteristics, dimensions, categories, elements and attributes. These terms are listed according to the degree of detail of the models to which they refer.

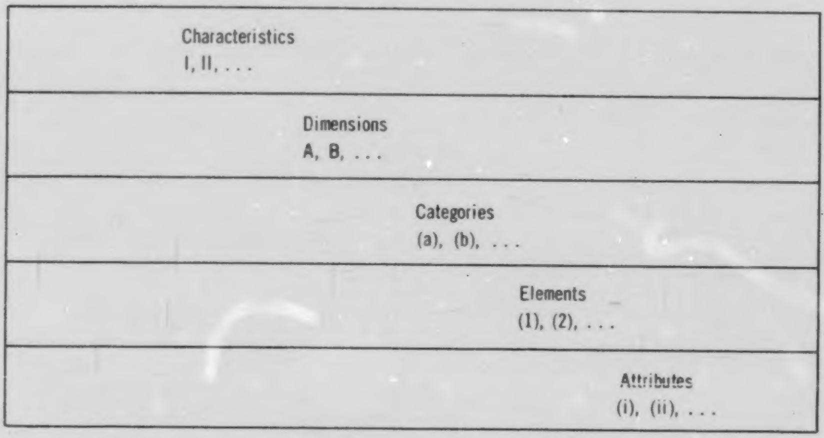
In the first instance, we can divide the models into four groups of broad characteristics: subject-matter, function, mode of analysis and source.

We can take any one of these characteristics and examine the model in terms of the various categories belonging to that particular set of characteristics. Within each of these broad groupings of characteristics we may consider models in terms of a number of dimensions. Within the group of characteristics associated with subject-matter for example, we can look at four dimensions of the subject-matter: the scope of the models, their coverage, the level of education with which they are concerned, or the type of education included. Again, in terms of the functional characteristics of models we have the dimension of the broad purposes of model-construction effort, on the one hand, and the specific role to which the models are put, on the other. As far as the analytic characteristics of the models are concerned, we can look at the dimension which is concerned with the orientation of the model, i.e. its properties as to its theoretical or applied nature. We can also look at the nature of the interrelationships incorporated in the model, i.e. independent, recursive or simultaneous.

Within each dimension we can list categories to which the models may be assigned. A further breakdown of the categories could be in terms of elements or sub-categories. For example, within the subject-matter dimension concerned with the scope of the models we can list three categories, namely, education represented by itself, related to other sectors, and institutional or micro-models. Within any dimension we assume that the categories or elements are mutually exclusive. This aspect enables us to distinguish categories and elements, on the one hand, and the attributes of models, on the other. A model may have more than one stated attribute, so that the attributes listed within any dimension are not mutually exclusive. For instance, concerning the mathematical form of equations such attributes as linear and non-linear equations may both be found within a given model.

Thus, the purpose of developing a detailed classification is to be able to order our universe of models and their various features, including the techniques and approaches used. The nature of the classification hierarchy is illustrated in the Figure III.1.

Figure III.1. CLASSIFICATION HIERARCHY



The remainder of the chapter describes the various parts of the detailed classification system in terms of the four broad characteristic groups. These groups are:

1. subject-matter characteristics (what is the model about?)
2. functional characteristics (what does the model do?)
3. analytic characteristics (what is the form of the model?)
4. source characteristics (who built the model?)

A detailed chart describing the complete classification system is provided at the end of this chapter and can be referred to by the reader throughout the remainder of this chapter.

2. SUBJECT-MATTER

The subject-matter characteristics of mathematical models of education can be viewed in terms of four dimensions. The first dimension is concerned with the scope of the subject-matter, that is the bounds that define the extent of our analysis of the subject-matter. The second dimension is concerned with coverage. The third dimension of subject-matter characteristics is the level of education. Conventionally, education is divided into a number of levels such as primary education, secondary education and higher education. The model-building effort could concentrate on an analysis of one or more levels of education. The fourth dimension is concerned with the type of education; for example, vocational education can be distinguished from general education.

Scope and Coverage

Within the subject-matter scope there are three categories of models. First, there are models that deal with the education sector by itself. Second, there are models that relate education to other social or economic sectors (manpower, production, health, etc.). Third, there are models whose scope is limited to the institution. On a different scale (coverage) we can show whether the model covers the education sector as a whole or covers only parts of that sector.

At this point we can suggest a cross-classification of scope with coverage; for example, whether education is represented by itself or is related to other sectors may be cross-classified in terms of its coverage of the education system. Models concerned with the flow of students within education may either cover the entire education system or be confined to only a part, such as the secondary school system. If we take the categories concerned with the scope of the model and cross-classify them with the categories concerned with their coverage we will have four possibilities, as illustrated in the Figure III.2.

Within the category called education represented by itself, there are five different elements in which the models belonging to this category can be distributed. First, there are the

Figure III.2. CROSS-CLASSIFICATION OF SCOPE WITH COVERAGE

Scope Coverage	Education by itself	Related to other socio-economic sectors
Parts of the education sector		
All of the education sector		

comprehensive education models. These models integrate two or more sub-sectors of a total education sector. For example, these models may calculate budgetary costs, teacher requirements, in addition to tracing the flow of students from one grade or level of education to another. When models are confined to setting up a student flow system, these have been identified as a separate group. A further group consists of student parameter models, these are concerned solely with explaining the level and changes in the transition coefficients of a student flow system. Models primarily concerned with the teacher demand and/or supply have been considered separately. Finally, all financial and physical resource models have been set up as yet another distinct group. This group is further sub-divided into:

i) those which deal with general costs;
ii) grants in aid from the economy; and
iii) school location models.

With regard to models where the education system is linked to other sectors we have proposed three elementary types. The first is called "comprehensive externally linked models". These attempt to cover the total economy, of which education and manpower are distinct parts. Secondly, there are models which attempt to establish the links between the manpower and the education sector without relating these in turn to the production sectors of the economy. In the last element we have included those models that determine the rate of return in education and use this as a rule for allocation and other policy decisions.

Finally, all models dealing with institutional management and planning problems in a general way are treated separately. The generalised institutional models covered by the survey are only illustrative of the work at this micro-level. These, in turn, could be split into three types: capacity models, resource requirement models and productivity models.

Levels

The convention of treating education in terms of levels has been adopted here, forming the third dimension within the subject-matter characteristics of the models. This will provide us with a number of attributes of models. Thus, models of education can deal with any combination of a number of levels such as primary, secondary and higher. Secondary education, in turn, can be split into upper and lower levels. From both the analytic and policy points of view the transition of students from one level to another is of considerable interest. Of course, the models themselves identify finer levels than have been indicated here in our classification system.

Types

Education can also be viewed in a fourth dimension in terms of the target group to which it is primarily directed. Models can therefore be identified in terms of the attributes of this particular dimension. The problem of national expenditures on education belongs to the type of education that is concerned with "all", while requirements of teacher training is a question for the special type of education. The information on the types of education (adult, technical, vocational, all, etc.) has been gleaned after examining the use of variables in the models. The five types of education distinguished are: vocational, technical, general, teacher training and "other" (adult, all, etc.).

When we consider the subject-matter of the mathematical models alone we have already identified a number of dimensions: scope (related to other sectors), coverage (part or whole), hierarchy (level), and direction or type /target group(s)/. Combinations of these provide us with a wide range of possibilities for the use of mathematical models in education. For instance, education can be studied in its relation to the wage structure in the labour market. This could be narrowed to professional education which could then be confined to postgraduate work regarded as higher education. The type of education could be teacher training. As a result we may have a model concerned with market demand for the output of professional graduate teacher training service.

Variables

Within the grouping of characteristics according to subject-matter we can examine the models of education from another viewpoint than the ones outlined above. We can classify models in accordance with their attributes as to the variables incorporated. Broadly speaking, we have three types of variables:

a) student variables in terms of numbers of stock or flow;
b) teacher variables in terms of numbers of stock or flow; and
c) other variables, primarily expenditures, capital stock and real and monetary cost variables.

Large and complex models of education, in principle, usually cover all these types of variables and formulate the interrelationships among them. In view of what has been said above, it is clear that some models may include those variables that cannot be characterised as being educational variables. In that case, the models would be considered as related to sectors other than education.

Sources and Types of Data

Four sources of data have been identified - population census, other regular surveys, special surveys and other sources. For the application of the model, both for the estimation of parameters and testing the relationships, a model may draw upon any or all of the data sources. Closely related to the sources of data is the question of the type of data and whether these are basically cross-sectional or time series.

Time Horizon

Finally, we can categorise models in terms of the time horizon that is assumed. Short-term is defined as less than five years, medium-term as five to seven years and long-term as more than seven years. These definitions are largely judgemental, and represent longer time spans than used in economics because of the longer time perspectives in education as compared with economic relationships. In addition, there are "static" models whose relationships may be time-indpendent.

3. FUNCTION

The second umbrella of characteristics under which we can outline a classification system is concerned with the functions of the model. Within this group of characteristics we can identify two broad dimensions: the general purpose of the model and the specific roles or uses of the model. In terms of our definitions, the purpose classification is closely related to the role classification. In fact, the specific uses have been identified in terms of the broad purposes of model-construction effort. Within the general purpose of providing forecasts the model may be used to provide specific forecasts of, say, new entrants or facility requirements. But since any model may have one or more specific uses, we cannot regard the detailed list of uses as elements. These specific uses have therefore been treated as attributes within the categories which describe the role of the model.

There are four major categories among which models can be distributed, namely descriptive, forecasting, decision and simulation. Even though there is no hard and fast rule justifying their separation it has been found that the models covered by the survey can reasonably be classified in this fashion. The problem, nevertheless, remains that the categories are excessively broad and need to be disaggregated in order to throw light on the functional characteristics of the model. Apart from the specific uses of the models mentioned above, this was possible to a limited extent only.

A descriptive model can be distinguished from others by the fact that it merely sets out the relationships of the system. The descriptive models need to be separated into two sub-categories in order to suggest whether the aim of the model is simply to describe or if it is concerned with analysis as well. A system of demographic accounts is a descriptive statement of the stocks and flows of humans in their learning and earning pursuits. On the other hand, the statistical correlation exercises per se, relating, say, earnings to education attainment, can be considered as analytic. This distinction, however, is arbitrary since there is no a priori reason to say that accounting relations (i.e. identities) lack analytic content while correlations per se have an analytic character. This distinction is made by distinguishing between the first two roles of the models, i.e. only to describe and to explain.

The category dealing with forecasting models needs to be further split in terms of the degree of conditionality imposed on the results of the forecasts. We can start with pure forecasts. These are statements regarding future expectations. They are made without reference to assumptions concerning related factors or variables other than those that are being forecast. Secondly, we can make conditional forecasts of the "if-so" kind. This implies that we arrive at estimates of future states on the assumption that certain tendencies will develop in the future. These are, at best, conditional statements about the future. Realisation of the forecasts depends on the realisation of the assumptions regarding future levels of certain other variables. If the assumptions are not validated, then, *pari passu*, the forecast figures will not be realised. Finally, we can speak of forecasting in the context of policy-making and control. Here, the implication is that one traces the consequences of certain policy decisions on the future state variables in addition to more or less exogenous development of some of the variables. This kind of forecasting in the context of policy impact on variables is somewhat difficult. This is so because the forecaster has to take into consideration two sets of factors simultaneously:

a) the actions of the decision/policy-makers and their impact on the forecast state;
b) other developments of variables which form part of the system being forecast. The inter-relationship between these two will then raise additional problems for the forecasting mechanism.

The third category in the purpose characterisation of models deals with the decision-making role of model-building. Here, the problem is not merely to generate a set of future estimates, which is the concern of the forecasting models, but to identify certain variables as policy variables and thereafter to solve for these variables in order that a solution can be proposed as the numerical values of the decision variables. The decision or policy variables are so regarded since they are under the direct control or the influence of the policy-makers.

The dividing line between forecasting and decision models is somewhat difficult to define since these are not mutually exclusive concepts and a model can have both these purposes. However, the possibility exists that a model can be identified with regard to its purpose by examining its primary role. The normative framework of a number of models clearly indicates their explicit role in decision-making in education. However, when a forecasting model merely has the possibility of being interpreted as a policy model because the forecasts could be used for decision-making, then there is no justification for classifying it as a decision model.

If the forecasting models can be regarded as having the "if-so" characteristic, the simulation model may be regarded as representing the "so-what" characteristic. The simulation models are defined as those that are characterised by a technique which permits conducting experiments and testing the behaviour of the system. Such testing and experimentation may or may not involve stochastic elements. We have been able to distinguish between simulation models that incorporate stochastic elements and those that do not. Very often, the simulation technique is employed in order to assist decision-making. Even so, we can distinguish the two since the role of a simulation model is to understand the complex behaviour of the system with a number of inter-acting variables, while a decision model essentially determines the values of decision variables in a normative sense.

We can now turn to role of models, i.e. the specific uses to which the models may be put. Here we have a large number of attributes of models, meaning that a model may have more than one specific use in terms of our list.

Use Attributes

Basing our information on the survey of mathematical models in education it has been possible to identify as many as 50 attributes of the models with regard to their specific use. These attributes can be grouped under the four purpose categories described above. Within the descriptive purpose category of models we have two major sub-divisions, namely models used only to describe educational phenomena, on the one hand, and models used to explain those phenomena, on the other. As regards purely descriptive uses, models may be used to describe the total education system, student stocks and flows, budgeting and finance, staffing and capital assets. On the other hand, model effort may be directed to explaining the behaviour of such variables as enrolments, graduation, success, costs, teacher variables, demand and availability of places, employment choices and the relationship between educational and other variables. With the aid of such a list it is possible to define in some detail the precise role of the models as far as description or analysis of the educational phenomena are concerned.

Having determined the forecasting purpose of models in terms of their primary function, it is possible to delve deeper in order to determine the variables for which forecasts are generated. In our classification scheme we have listed 13 such variables that can be regarded as attributes of the forecasting models.

We have defined decision models as those where the variables that are solved for can be regarded as decision or policy variables. But these decision variables can be classified as those concerned with global decisions, on the one hand, and those concerned with partial decisions, on the other. Global decisions in turn can be sub-divided into those that affect the education sector only or those which are inter-sectoral in nature, in the sense that they cover not only the education sector but the manpower and economic sectors as well. Partial decisions may be concerned with the allocation of students, allocation of teachers, allocation of physical and/or financial resources, problems of optimal size and time phasing.

Finally, the purpose category defined as simulation lends itself to the following interpretation concerning the use of such models. In a general sense, simulation exercises can have either the training use only or an analytic use as well. In order to identify meaningfully the attributes of the analytic uses of simulation exercises, we have chosen a special way to describe this. In view of the nature of simulation exercises, we can consider the attributes in terms of postulating alternative values of some specific variables in order to determine their effects upon another set of variables. Therefore, we have divided the attributes into the group of variables that are assigned alternative values, as distinct from another group of variables to be considered as effect variables. Thus, we can identify from the list of attributes a model which examines the effect of alternative values of enrolments upon teacher requirements or costs and expenditures. Another example would be a model which analyses the effect of alternative values of teacher salaries on teacher availabilities and the production of graduates.

4. MODE OF ANALYSIS

The mode of analysis is concerned with the form of the model and, as a result, this characteristic grouping includes all the technical aspects of model construction and use. In a very general sense, and overlapping with the functional categorisation of models, we can identify the dimension that may be regarded as the orientation of the model. The primary orientation of the model can be categorised in any one of the three categories:

1. theoretical and algebraic;
2. numerical and experimental;
3. numerical and applied (in the sense of utilising empirical data).

These categories are self-evident. As could be expected, most of the models surveyed can be regarded as being numerical and oriented towards application in concrete empirical situations.

Having categorised the orientation of the model we can now turn to the mathematical form of the model by examining the nature of the relationships. In this way, we can study a number of attributes of mathematical models in education in respect of their technical characteristics. Two major types of attributes of the relationships that can be readily identified are:

a) the substantive meaning of the equations of the model; and
b) their mathematical shape.

The phenomenon that a relationship or an equation describes, such as the behaviour of a consumer, is distinguishable from the shape of that relationship which may be linear, non-linear or log-linear. Another set of attributes of models pertains to the dimension which has to do with the nature of the equation system as a whole.

Substantive Meaning

Using the taxonomy proposed by Jan Tinbergen in his Theory of Economic Policy, (North Holland Publishing Co., Rotterdam, 1952), we have identified equations of the models as behavioural, technological, legal-institutional and definitional. The legitimacy of the application of the Tinbergen taxonomy, developed in the context of the macro-economy, to the problems of education is, of course, questionable. This is particularly so when one accepts the distinction between behavioural and technological equations. A major part of economic analysis, as has been mentioned before, is concerned with the process of production of material objects, and the analysis of this process is conducted in terms of the technological production function. By analogy it has been claimed that the output of education is qualified personnel and this process can be analysed with the help of the production function as well. The fundamental difference often overlooked is that while the relation between input and output of a physical production process is largely technological, the governing factors in the output of qualifications resulting from learning are, by their very nature, behavioural. Consequently, the proportionality assumption, for instance, between the input of ore and the unit output of steel is not valid for, say, the input of teacher time and the acquisition of the Ph.D. degree, notwithstanding the problems of quality. This does not mean that models of education cannot, by definition, have technological relations. The relationship between classroom area and seating capacity can be assumed as technological and similar relationships have been specified in some of the models surveyed. These kinds of relationships can be legitimately claimed as technological whereas a transition coefficient, for example, is behavioural in its nature.

In the case of legal-institutional relations the problem of identifying these is perhaps less serious. In the models of the economy it is possible to consider, for example, a tax rate equation to be of this kind, and in models of education a ceiling of admissions introduced as a constraining relation can be similarly claimed as legal. Lastly, the accounting equations or identities are useful and convenient devices for consistency-checking.

Shape

The shape or mathematical form of the equations can be classified into six groups, as follows:

a) i) Equalities
   ii) Inequalities
b) i) Deterministic
   ii) Stochastic
c) i) Instantaneous
   ii) Lagged first order
      [e.g. $y_t = f(x_{t-1})$]

iii) Lagged second or higher order
[e.g. $y_t = f(x_{t-2})$]
d) i) Linear
ii) Non-Linear
e) i) No difference
ii) First-order difference
e.g. $y_t = f(\Delta x_{t-j})$
$y_t = f(dx_{t-j})$
iii) Second or higher-order difference
e.g. $y_t = f(\Delta^2 x_{t-j})$
$y_t = f(d^2 x_{t-j})$
f) i) Continuous
ii) Discrete.

Nature of the Equation System

Apart from characterising individual relationships of a given model, it is useful to look at the equation system as a whole since all equations are brought into play when we need to obtain a solution. In the first place, when the model is formulated in a mathematical programming framework then some kind of an optimisation criterion needs to be introduced to obtain a unique solution. We call this criterion a preference function and distinguish this dimension of the models by the introduction of this feature. Among optimisation models we can distinguish those that use a linear or non-linear preference function to obtain the unique solution.

The system of equations of a model can be a combination of independent equations (solved individually), recursive (solved one after another), simultaneous (solved together by matrix manipulation) and block recursive (solved in blocks of simultaneous equations, one block after another). We have distinguished the models in terms of these attributes of the equation systems.

Estimation Techniques and Problems

Another dimension of the mode of analysis characteristic of mathematical models in education is concerned with the statistical or empirical form of the models. The first consideration here is the basis on which the parameters governing the relationships are estimated. While model-building in economics has relied heavily on statistical-econometric methods for the estimation of the values of parameters, this is not necessarily so in other fields. Engineering, medicine and health are some of the sectors where model-building effort has drawn upon expert opinion to a very large extent. In the case of earth sciences, transport, physical environmental studies, special tabulation may well provide an important basis for the estimation of parameters. In education one may expect a wide range of methods to be employed because of the weakness of the data base.

There are four bases estimating the values of parameters and all or any could be used in a particular model. These are: econometric/statistical analysis, data tabulations, impressions of experts and various other methods which fall outside the former three. As regards the techniques of estimation, the most commonly used would be simple regression, multiple regression and a number of multi-variate techniques developed in the context of psychological and health research. Another way of looking at the attributes of the model in relation to parameters is whether the variation in parameters is made an important part of the investigation. These variations may be examined in the temporal or historical sense. Ex-post changes in parameters over time could be studied to evaluate the reliability of the estimates and the need for their up-taking. Ex-ante changes in parameters can be examined to test the sensitivity of the values of the variables to given changes in the values of the parameters. Since mathematical model-building is still in its infancy with respect to education it would be surprising to encounter any major effort in these directions, nor can it be expected that any substantial work on error analysis is being carried out, despite the fact that some of the models of education involve large amounts of complex numerical calculations subject to serious "noise".

5. SOURCE

The fourth major characteristics grouping of the models is in terms of the institutional affiliation of the model-builder. Seven sources of model-construction effort have been identified as categories among which the models may be distributed. They are:

a) principal government organisation responsible for education;

b) national statistical office;

Table III.3

CLASSIFICATION SCHEME FOR MATHEMATICAL MODELS OF EDUCATION

Characteristics	Dimensions	Categories	Elements/Attributes	Sub-elements/ Sub-attributes
I. Subject-Matter	A. Scope	(a) Represented by itself	(1) Comprehensive (2) Student flow (3) Student parameters (4) Teacher demand and/or supply (5) Finance and physical resources	(i) General costs (ii) Grants economy (iii) School location
		(b) Related to other sectors	(1) Comprehensive externally-linked (2) Manpower-linked (3) Returns to education	
		(c) Institutional (micro) models	(1) Capacity (2) Resource requirements (3) Productivity	
	B. Coverage	(a) The education sector as a whole (b) Parts of education sector		
	C. Level		(1) Primary (2) Lower secondary (3) Upper secondary (4) Higher	
	D. Type of education		(1) Vocational (2) Technical (3) General (4) Teacher training (5) Other	
	E. Variables included		(1) Student stocks (2) Student flows (3) Teacher stocks (4) Teacher flows (5) Expenditures (6) Capital stock (7) Costs	
	F. Sources of data		(1) Population census (2) Other regular surveys (3) Special surveys (4) Other sources	
	G. Types of data		(1) Cross-sectional (2) Time series	
	H. Time	(a) Short term (b) Medium term (c) Long term		

			(2) Explanatory	
		(b) Forecasting	(1) Pure forecasts-(expectations) (2) Conditional forecasts (if so) (3) Policy-making and control	
		(c) Decision-making (d) Simulation	(1) With stochastic elements (2) Without stochastic elements	
	B. Role	(a) Only to describe	(1) Total education sector (2) Student stocks and flows (3) Budget and finance (4) Teaching staff and other Personnel (5) Capital stock and other physical facilities	
		(b) To explain	(1) Enrolments (2) Production of graduates (3) Success rates and/or drop-outs (4) Costs and/or expenditures (5) Teacher requirements (6) Teacher availabilities (7) Demand for places (8) Availability of places (9) Employment choices (10) Relationship between education and economic variables	
		(c) To provide forecasts of	(1) Enrolments (2) Production of graduates (3) Success rates and/or drop-outs (4) New entrants (5) Costs and/or expenditures (6) Teacher requirements (7) Teacher availabilities (8) Facility requirements (9) Facility availabilities (10) Demand for places (11) Availability of places (12) Manpower requirements (13) Manpower availabilities	
		(d) To solve for the values of variables for	(1) Global decisions	(i) Education sector only (ii) Inter-sectoral (education, manpower and the economy)
		(e) Simulation exercises for training	(2) Partial decisions	(i) Allocation of students (ii) Allocation of teachers (iii) Allocation of physical and financial resources (iv) Optimal size (v) Time phasing of decisions

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Table III.3

CLASSIFICATION SCHEME FOR MATHEMATICAL MODELS OF EDUCATION (Cont.)

Characteristics	Dimensions	Categories	Elements/Attributes	Sub-elements/ Sub-attributes
II. Function (cont.)		(f) Simulation to determine the effects of alternative values of	(1) Enrolments (2) Success rate and/or drop-outs (3) Teacher salaries (4) Teaching programmes and/or schedules (5) Examination procedures	
		Upon	(1) Elements (2) Production of graduates (3) Costs and/or expenditures (4) Teacher requirements (5) Facility availabilities (6) Class sizes (7) Manpower availabilities	
III. Mode of Analysis	A. Orientation of the model	(a) Theoretical and algebraic (b) Numerical and experimental (c) Numerical and applied		
	B. Substantive meaning of the equations		(1) Behavioural (2) Technological (3) Legal-institutional (4) Definitional	
	C. Shape		(1) Equalities (2) Inequalities (3) Deterministic (4) Stochastic (5) Instantaneous (6) Lagged first order [e.g. $y_t = f(x_{t-1}$] (7) Lagged second or higher order [e.g. $y_t = f(x_{t-2}$] (8) Linear (9) Non-Linear (10) No differences (11) First order differences [e.g. $y_t = f(\Delta x_{t-j})$; $y_t = f(dx_{t-j}$] (12) Second or higher order differences [e.g. $y_t = f(\Delta^2 x_{t-j})$; $y_t = f(d^2 x_{t-j}$] (13) Continuous (14) Discrete	

	D. Nature of the equation system		(1) Independent (2) Recursive (3) Simultaneous (4) Block recursive	
	E. Optimisation	(a) Preference functions (b) Other	(1) Linear (2) Non-Linear	
	F. Estimation techniques and problems	(a) Basis for parameter estimation	(1) Econometric/statistical analysis (2) Data tabulations (3) Impressions of experts (4) Other methods	
		(b) Estimation techniques	(1) Simple regression (2) Multiple regression (3) Other alternative techniques (4) Other	
		(c) Changes in parameters	(1) Ex ante changes (sensitivity analysis) (2) Expert changes (reliability analysis)	
IV. Source, Organisation, Status and Finance	A. Source of model-building effort	(a) Principal government organisation responsible for education (b) National Statistical Offices (c) Other government office (d) University (e) Other non-governmental organisations (f) International organisations (g) Individuals not related to the above		
	B. Use of the results	(a) Acceptance by government (b) Non-acceptance by government		
	C. Source of finance		(1) Government (2) Universities (3) Independent bodies and research institutes	
	D. Status of work	(a) Finished (b) In progress (c) Planned		

c) other government office;
d) university;
e) other non-governmental organisation;
f) international organisation;
g) individuals not related to any of the above.

The affiliation of the model-building effort and its use are closely interrelated. If a mathematical model has been constructed by or for a government agency, then one can expect that the exercise was carried out with a view to its possible use and application The question of the actual acceptance of the model results by any government is difficult to answer. Nevertheless, this is a matter of judgement and a reasonably correct answer to this question can be obtained with some cross-checking and feedback. It will be of some interest to describe the procedure by which such information was obtained.

First, the respondent was asked a "yes-no" question as to whether the results indicated by the model were accepted at an official level. By this it was maintained that the responsible officials in the government considered the results as valid for use in their decision-making. If the response to this question was positive then the questionnaire attempted to find out by whom the results were so accepted. In the case where the results were not accepted, the questionnaire attempted to find out why not. Finally the respondents were asked to give a brief description of of how the results of the model were being used. Such information can be used and interpreted to suggest a categorisation of models in terms of the relationship between the model-builder and the application of his effort.

The attributes concerning the sources of finance are broken into government, universities and other independent bodies. The status of work categorisation is in terms of work finished, in progress or definitely planned.

Chapter IV

HIGHLIGHTS

1. AGGREGATE ANALYSIS OF MODELS

The classification described in the foregoing chapter may be used as a map to scout the terrain in any detail; it will be useful to study in the aggregate a few landmarks as represented by the most important methods, approaches and techniques employed in the model-building effort. To continue with a metaphor, it is not difficult to observe that the terrain, though limited, is very much uneven. Our map has included a very wide range of mathematical models and techniques associated with them. At one extreme we have large and complex models that include many hundreds of variables covering not only the education sector but also its links with other socio-economic sectors. On the other end of the spectrum we have simple regression exercises correlating pairs of variables to test plausible hypotheses in education at a macro-or micro-level. Between these extremes we find models tailored to specialised problems such as transport of children from home to school, on the one hand, and generalised simulation programmes which can accept a body of data to generate solutions under different assumptions, on the other. In each case a number of specialised techniques are utilised to tackle the problems under investigation. Thus, the body of available information on the mathematical models of education represents a difficult terrain to cross. We therefore need to take a first overview before launching on the tiresome expedition. Using our classificatory map we can point out the important and noticeable peaks as well as the general groundswell of the territory of mathematical models in education.

For this purpose we shall rely on an "aggregate analysis". By this we mean that our first examination will entail no greater detail than a head-count of the models. We shall simply make statements concerning the various characteristics and categories to which the models belong. For example, it will be interesting to find out the number of models whose primary purpose is to forecast the variables under study, or the number of models that have been constructed within universities as distinct from governmental and other non-governmental agencies. Such information and analysis could, at best, be regarded as a first approximation to a more detailed study of the nature and direction of the model-building effort.

Even as a preliminary view of the pattern of activity in the field, the mere count of models may be misleading. This is because no differential weight is given to models with differences in size, complexity, relevance and practical application. As we have already noted, the body of models represents wide variations in almost all respects.

Despite these caveats we have attempted to provide an overall picture in the hope that such an aggregate analysis will not distort the features that will emerge from an examination of the details of individual models. Because of the fact that there are as many as 122 models surveyed, it is unlikely that the distortions resulting from an analysis based on the count of models will be quite large. Therefore the findings contained in this chapter can be accepted subject to some strict qualifications.

2. FEATURES

Subject-matter Features

To provide an overview of the 122 models of education surveyed here we have made a tabulation (Table IV.1) which distributes these models among the categories belonging to each of the four groups of characteristics of the model-building effort. The subject-matter categories are listed on the left of the table. The categories belonging to the functions of the models, the mode of analysis employed and the sources of model-building effort are listed across the top of the table. The table, in effect, cross-classifies the models by subject-matter categories, on the one hand, and by other categories, on the other.

Taking a first look at the table, we may focus our attention on the initial column and the terminal row. Column 1 gives a breakdown of models by subject-matter categories and elements.

Table IV.1

DISTRIBUTION OF MODELS ACCORDING TO CHARACTERISTICS

SUBJECT MATTER OF MODELS	TOTAL	FUNCTION OF MODELS				MODE OF ANALYSIS			SOURCE					
		Descriptive/Analytic	Forecasting	Decision	Simulation	Theoretical Algebraic	Numerical and experimental	Numerical and applied	Principal Government organisation responsible for education	National statistics office	Other Government offices	Universities	Other non-government	International organisations
Education system represented by Itself	67	11	35	16	5	4	6	57	24	2	12	20	8	1
Comprehensive education models	6	-	4	1	1	1	-	5	1	-	-	3	1	1
Student flows	23	2	18	1	2	2	2	19	7	2	8	6	-	-
Determination of rates of flow and other student parameters	8	7	1	-	-	-	1	7	1	-	1	4	2	-
Teacher demand and/or supply	13	1	7	3	2	1	2	10	8	-	-	2	3	-
Physical and/or financial resources	17	1	5	11	-	-	1	16	7	-	3	5	2	-
Education related to other sectors	37	7	19	7	4	1	5	31	5	-	16	8	5	3
Comprehensive externally-linked	15	2	5	4	4	1	2	12	2	-	7	3	-	3
Manpower linked	18	1	14	3	-	-	2	16	3	-	9	3	3	-
Returns to education	4	4	-	-	-	-	1	3	-	-	-	2	2	-
Institutional models	18	6	3	3	6	-	-	18	6	-	-	11	1	-
TOTAL	122	24	57	26	15	5	11	106	35	2	28	39	14	4

Source: Annex 2, "Basic Characteristics ...".

Broadly speaking, the tabulation indicates that the absolute majority of models surveyed represents the education sector by itself, that is, without establishing explicit links with any external sector. Among the exclusively educational models we have six "comprehensive" models of the education sector. Another group of models dealing exclusively with the education system is concerned with the flow of students through the education system. This is by far the largest group, which emphasizes the point we have made before that the model-building effort has been largely of a structuralist nature rather than of a behaviouralist nature. Given the rapid expansion of numbers of students, particularly in the post-secondary education sectors, model-builders have focused their attention on the internal dynamics of the educational system, using the so-called transition matrix in order to make better forecasts of enrolments at the various educational levels. In a large number of cases, and in fact across the board, the educational system has been described in terms of a student transition proportions matrix.

The problem of finding reliable explanatory factors that determine the parameters of the student flow model is intimately related to the setting up of a student flow system for forecasting and decision-making. We have, however, distinguished the student parameter models as a separate group in order to highlight some special problems involved in finding the significant causal relationships governing the input, throughput and output of students in a system. We have been able to identify eight models that may be regarded as student parameter models. By and large, however, there appear to be too few explanatory models of the various parameters of the student flow system. This gap appears particularly glaring in view of the fact that there is an extensive interest in the dynamics of student flows as the basis for most of the educational model-building effort. Clearly, the overall student flow model-building effort seems to have outrun our understanding of the specific factors influencing the rate and direction of the flows of students in the system.

There are thirteen models which deal primarily with problems of teacher demand and supply models process. The interest in the teacher demand and supply models stems from two developments. First, there is the major quantitative expansion of enrolments which has resulted in a great shortage of teachers in a number of countries. Second, there is the rising cost of education. One aspect in this connection is that the teachers' salaries, which constitute a very large portion of any school's current account budget, have increased relative to the prices of other inputs into the educational process. This has raised the question of substitution between the trained teachers and other auxiliary help, on the one hand, and between labour and capital inputs, on the other.

The next group of models concerned exclusively with education are the resource models. The subject-matter of what we have called resource models is very diverse. Because of their policy orientation there is a high degree of official interest in these models. There are 17 resource models covered by the survey. We can divide these into three groups:

a) general cost models;
b) grants economy models;
c) school location models.

Whenever a model attempts explicitly to relate the education sector to other sectors like manpower and economy, we have treated this separately. In most cases the external links are with the manpower system. Historically, the skill formation function of education has been greatly emphasized, with the consequence that the role of education was exclusively confined to the production of necessary manpower. The requirements of the various types of manpower were of course determined by the evolution of the structure of the economy. Only recently, increasing importance is being given to the autonomous role of education where education is considered as a consumer good to which any individual as a member of society has a right. (A more radical approach towards education is to regard educational institutions, especially universities, as serving the "critical function" in society, and producing agents for social and institutional change. Be that as it may, the model-building effort has not, and is probably unlikely to, take account of these far-reaching qualitative questions concerning the educational system as a part of a larger social system.)

Altogether there are 37 models that may be regarded as open in the sense that they relate education to other sectors. In the case where an attempt is made to cover the economy and the manpower sectors as a whole - together with the education sector - in a consistent manner, we have treated such models as "comprehensive externally linked" models. There are 15 models of this type.

A straightforward manpower approach is evidenced in 18 mathematical models of education. Clearly, to our list of the externally linked models should be added those models concerned with returns to education. These are largely designed to determine the demand for education of an individual in terms of his attempt to maximise the discounted sum of his expected life-time income stream. There are no more than four models of this kind covered in the survey.

Model-building at the level of institutions varies considerably in the degree of complexity. A few of the models are quite simple forecasting models, their aim being to give forecasts for, for instance, future student enrolment and teacher requirements. Others are more advanced simulation models with a great number of variables. The purpose of the latter is to stimulate the effect on certain endogenous variables (e.g. student enrolment, current costs, the "quality of education", etc.) by changing some exogenous and/or policy variables. There are as many as 18 institutional models which may be roughly divided into three groups according to their subject-matter content: capacity models, resource requirement models and productivity models.

Functional Features

For an examination of some of the other features of mathematical models of education we can turn to the terminal row of the table. The tabulation of the functional features of models is based on the respondent's own interpretation of his work as to whether the model was considered as descriptive/analytic, forecasting, decision-making or simulation. The descriptive model is defined in the questionnaire as that which merely sets out the relationships of the system. On the other hand, the forecasting model is primarily concerned with generating a set of future estimates. A decision model is one in which policy variables are solved for (or the desired levels of which are indicated as a result). Finally, those models characterised by the technique of simulation are a special case of descriptive models but were distinguished separately because of their special properties. The simulation technique allows one to conduct experiments in testing the behaviour of a system. In the technical sense of the term, this invariably involves stochastic elements, but it is also possible to interpret experimentation as simulation when we are not concerned with probabilistic properties of variables or parameters.

An overwhelming majority of the models is considered primarily as forecasting models. All in all, a little less than half the models (57 out of 122) covered by the survey are described as "forecasting models". Decision-making, however, has a much less important role. We find 26 models of this kind. As few as 24 models are categorised as descriptive and/or analytic. Finally, there are 15 cases in which the use of the technique of simulation is the chief characteristic of the model. From among the simulation models we were able to find only a couple of instances in which stochastic processes were utilised.

The cross-classification of this four-way division of models in terms of their functional categories with the 3-category, 9-item subject-matter classification is of considerable interest. In the case of models exclusively concerned with education, there are only 4 simulation models out of 67. But, in the case of models of educational institutions (and here we are speaking only of the generalised institutional models) one third of the models are characterised by the use of the simulation approach. Simulation has also played an important role in the externally-linked comprehensive models. The sizes and complexity of global systems are possibly the most important reason for using simulation as a method for understanding the complex interactions among the vast number of variables. As may be expected, decision models were predominantly found in the case where resource allocation constitutes the subject-matter. Eleven out of 17 resource models are characterised as having decision-making as the most important ingredient.

Descriptive or analytic types of models are used extensively for the subject-matter where the behaviour of the parameters of the student flow model are explained. Also, all the models concerned with the returns to education have been regarded by their authors as descriptive or analytic. One third of all the institutional models have also been considered as descriptive or analytic.

We now come to the forecasting models. Eighteen of the 23 student flow models are regarded as forecasting models. In the case of models whose subject-matter deals with teacher demand or supply, seven out of 13 are primarily concerned with forecasting. Four out of 6 comprehensive education models are forecasting models. Only in the case of resource models do we find that the role of forecasting is far less important than that of decision-making; as a result, only five of the 17 models deal primarily with forecasting. Forecasting has also played a most important role in the case of models linking education to other sectors.

Fourteen out of the 18 manpower linked models are concerned with forecasting, but only five of the 15 comprehensive externally linked models are designed for forecasting.

Analytic Features

The basic question concerning the analytic features of the models is to determine whether the model is primarily theoretical-algebraic, numberical-experimental, or numerical and applied. The tabulation of the responses clearly shows that the overwhelming majority of models can be considered as exercises in empirical application. The fact that most models have been applied, in the sense of using actual data, does not necessarily mean that their immediate usefulness has in any sense been demonstrated. Because of the newness of this whole field of investigation, there is actually little evidence that model-builders have considered application as a continuous process of testing and evaluating the model forecasts and carrying out the necessary revisions to keep the models up to date. Most model-builders would probably regard their work as experimental even when they have used actual empirical data to generate potentially usable results. It is therefore necessary that we interpret the tabulation with caution.

Source of Model-Building Effort

The majority of the models have emerged from government institutions, i.e. 67 models. Of these government-based models 35 have been developed in the ministries of education. Only two of the government-based models claim to have been worked in the national statistical offices. This lack of interest in model-building by the statistical offices is surprising and may be due to the fact that these offices have attached greater priority to obtaining standardised and reliable statistics as a first stage before launching into model-building exercises. Among the non-governmental institutions, the universities, as one would expect, have played the major role in education model-building. A third of the models constructed within universities are, however, institutional models. There are 13 models of which other non-governmental organisations, such as research institutes and foundations, are directly responsible. Only three models appear to have been housed in international organisations.

There are three subject-matter categories in which we find a concentration of the interest of government education departments with regard to model-building. These are student flow systems, teacher demand and/or supply, and resource problems. The models from statistical offices deal exclusively with student flow systems. Other government offices, such as departments of finance and planning offices, have concentrated their attention on student flow systems. But these offices have also been largely interested in linking education to other sectors. Sixteen of the 30 models housed in other government offices have worked on the external links between education and other sectors.

Universities seem to have worked on all the subject areas identified here with by far the greatest interest in institutional models. International organisations, both UNESCO and the OECD, have worked on comprehensive models and have not so far extended their efforts to more specific problems and aspects of the education sector.

3. ATTRIBUTES

We have so far highlighted the models in terms of the various categories and elements of the classification system. We will now take up the attributes of the models and attempt to highlight these in terms of the frequency of their occurrence as regards the entire model-building effort. It will be recalled that while the categories and elements were grouped under four heads, the attributes of models were basically of three types. The first type of attributes of models belongs to the subject-matter characteristics. Here we listed a number of variables or types of variables that could be considered as the subject-matter attributes of the model. Secondly, we listed a number of specific technical features of the mathematical relationships as attributes of the analytic kind. Finally, we listed a large number of functional attributes concerning the specific uses of models. These three types of attributes will be examined separately in order to provide the highlights of this aspect of the model-building effort.

Subject-Matter Attributes

Subject-matter attributes are essentially the variables included in the models. Generally speaking there are three types of variables: student variables, teacher variables and others comprising expenditures, capital stock and cost variables. The student variables as well as the teacher variables can each be further sub-divided into stock variables and flow variables. The stocks describe the numbers at any given point of time, the flows are measured in terms of rates of change during a specified period of time.

The frequency of the occurrence of these variables in the total stock of models has been tabulated in table IV.2. The table also provides information on the way in which these variables have been used by cross-classifying them with the level of the education sector covered by the model. Thus, at the top of the table we have identified the use of the variables and on the left of the table we have listed the various levels of the education sector with which the model is concerned. The listing of models in each of the four sections of the table comprises items which are mutually exclusive. This enables the count of models in each section of the table to add up to the total number of models according to the use of the variables in total, without distinguishing the level of education with which the variables are concerned. As could be expected, 111 of the 122 models include the stock and/or the flow measures of student variables. Of these, 35 models are concerned with stock of students only and 13 are concerned with the flow of students only; the remainder, i.e. 63 models, are concerned with both stocks and flows of students.

Models concerned with student variables are most frequently found for the higher education level. A lesser number of models is concerned with student variables at all other levels of education.

As far as teacher variables are concerned, 63 of the 122 models include these variables. Hardly any model is concerned exclusively with the flow of teachers. The majority of the models seems to be concerned with the stock of teachers alone. It is interesting to observe that among those models which are concerned with higher education only, fewer include teacher variables. Only 20 of the 43 models of higher education include teacher variables. Teacher variables are more frequently found in models not exclusively concerned with higher education.

The frequency of occurrence of teacher and student variables in models seems to be greater than other variables such as expenditures, capital stock and costs. In the case of models dealing exclusively with higher education, however, we find that the majority of cases include variables of this latter kind. In

Table IV.2

VARIABLES INCLUDED IN THE MODEL CROSS-CLASSIFIED BY LEVELS OF EDUCATION COVERED BY THE MODEL

Levels of Education covered by the Model	Total number of models	STUDENT VARIABLES				TEACHER VARIABLES				EXPENDITURES, CAPITAL STOCKS AND COST VARIABLES							
		Stocks only	Flows only	Both Stocks and Flows	None	Stocks only	Flows only	Both Stocks and Flows	None	Expenditures only	Capital stocks only	Costs only	Expenditure and capital stocks	Expenditure and costs	Capital stocks and costs	Expenditures, Capital stocks and costs	None
Primary only	1	1	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0
Lower Secondary only	2	1	0	1	0	0	0	1	1	0	0	0	1	0	0	0	1
Upper Secondary only	5	1	1	3	0	3	0	0	2	1	1	0	0	0	0	0	3
Higher Education only	43	12	4	24	3	11	0	9	23	5	2	3	2	4	1	6	20
Primary and Lower Secondary	2	1	0	1	0	1	0	0	1	0	1	0	0	0	0	0	1
Primary, lower and upper secondary	20	8	1	7	4	4	0	6	10	0	3	0	2	0	0	3	12
Lower and upper secondary	7	5	0	1	1	3	0	2	2	0	0	0	0	0	1	0	6
Lower and upper Secondary and higher education	4	0	0	4	0	1	0	2	1	0	0	0	1	0	0	0	3
Upper secondary and higher education	4	0	3	1	0	1	0	1	2	0	0	0	0	3	0	1	0
All Educational levels	34	6	4	21	3	6	2	9	17	2	1	2	2	2	1	3	21
Total	122	35	13	63	11	31	2	30	59	9	8	5	8	9	3	13	67

this case, expenditure variables seem to dominate the group. Overall, no more than 57 of the 122 mathematical models of education include variables of this type.

The general picture that emerges from such a review is as follows. Most models are concerned with student and teacher variables, with lesser attention being given to economic variables. In the case of the use of these human variables, relatively greater emphasis has been placed on stocks as distinct from flows. The most frequent use of the economic variables seems to be in the higher education sector treated by itself.

Analytic Attributes

To illustrate the analytic attributes of the models we have provided a table which cross-classifies the models that include relationships of the designated type, on the one hand, and a four-way classification of models according to their functional purpose, on the other. On the left side of the table we find four rows identifying the purpose of the model: descriptive, forecasting, decision-making and simulation. The top of the table is divided into two sections. The first section deals with the substantive meaning of relationships and the second section deals with the shape and structure of those relationships. The terminal row of the table gives the total number of models which display the attributes under the two broad sub-headings mentioned above.

As regards the substantive meaning of the relationships, it will be recalled that we have adopted the Tinbergen taxonomy of describing the relationships, namely, behavioural, technological, legal-institutional, and definitional. From the table we can note that of the 122 models, 62 models included relationships of the behavioural kind, either exclusively or in combination with any of the other three types of equations. Forty-eight models for which information of this kind was available have not included any behavioural relationships whatsoever. No information was available for the remaining 12 models. It is somewhat surprising that such a large number of models is completely devoid of behavioural relationships. This highlight of the model-construction effort supports our hypothesis that the structural approach plays a predominant role in model-building in education. If we look at the model count in terms of its distribution among the various purpose categories of models, it is surprising to note that more decision models were constructed without behavioural

Table IV.3

NATURE OF MATHEMATICAL RELATIONSHIPS CROSS-CLASSIFIED WITH FUNCTION OF MODEL

Purpose categories of models	Total number of models	SUBSTANTIVE MEANING OF RELATIONSHIPS				SHAPE AND STRUCTURE OF RELATIONSHIPS									
						Linear and non-linear equations					Nature of human relationships				
		Behavioural only	In combination with others (technological, legal institutional and definitional)	Without behavioural relations	No Information	Linear equations only	Non-linear equations only	Both linear and non-linear equations	Models with no information	Total number of models which include linear relationships	Independent equations	Recursive equations	Simultaneous equations	Block-recursive equations	Models with no information
Descriptive models	26	7	10	4	5	13	1	10	2	23	14	1	6	1	1
Forecasting models	58	3	29	23	3	48	2	6	2	54	24	16	8	6	0
Decision models	24	2	7	11	4	15	1	4	4	19	8	0	3	1	7
Simulation models	14	1	3	10	-	8	1	4	1	12	3	3	2	1	3
Total	122	13	49	48	12	84	5	24	9	108	49	20	19	9	11

relationships than with behavioural relationships. This is even more strikingly apparent in the case of simulation models. Together both the decision and simulation models are relatively devoid of behavioural relationships. In the two categories, 21 models can be identified as containing no behavioural relationships of any kind, while only 13 models include behavioural relationships alone or in combination with other relationships.

As regards forecasting models, we also noticed that a surprisingly large number of models do not include any behavioural relationships. Twenty-three of the 58 models are constructed without behavioural relationships while 32 models include behavioural relations. The descriptive analytic models, because of their nature as explanatory devices, include a predominantly large proportion of behavioural relations. Seventeen of the 21 models for which information of this kind was available included behavioural relationships by themselves or in combination with other relations.

The second part of the table shows the shape of the equations; there are no more than 29 models which include non-linear relations. This is not surprising since the inclusion of non-linearities in models with simultaneous equation systems creates difficult problems of obtaining solutions. Furthermore, the assumptions on which the equations are set up usually do not permit us to incorporate non-linearities into the construction of the model. It is therefore interesting to note that models containing non-linear equations are mostly of the descriptive-analytic nature, which confirms the first reason we have given for the unpopularity of non-linear relations. If we now look at the equation structure as a whole we find that models that include linear equations are by and large characterised by independent equations. As many as 49 of the 108 models include independent equations. Almost an equal number of models are characterised by recursive equations and simultaneous equations. As many as 16 models that use recursive systems of equations are of the forecasting type. Only half that number are simultaneous equation systems used for forecasting purposes. It appears that most of the forecasting effort is based on the use of independent equations. This is so since 24 models, including independent equations, are used for the purposes of forecasting. Descriptive and analytic models also are those that contain independent equations in a large number of cases.

In general it is apparent that the model-building effort with different purposes continues to rely on the use of independent equations, reflecting the fact that education has not been analysed in sufficient depth to enable the specification of interrelationships among the different phenomena which would permit the use of simultaneous or recursive systems of equations. The evolution of econometrics can be used as an illustration for anticipating a similar development in the use of mathematical models in education. We may suggest that the likely trend in the future of model-building effort will be the construction of more complex models which specify simultaneously interdependent equation systems, in order to reflect the complexities of the real situation in education.

Functional Attributes

It will be recalled that within the four purpose categories - descriptive, forecasting, decision and simulation - we have identified a number of attributes concerning the specific uses of the models. In the accompanying table the 51 attributes have been listed at the top of the table. On the left-hand side we show the different levels of the education covered by the model. There are ten subject-matter categories concerning the level of education, such as primary, secondary, higher education, etc. Thus, we have cross-classified the specific uses of the models with the level of education covered by the models. The terminal row of the table shows the frequency of the uses of the models in terms of our use attributes. For example, two models out of 122, among other things, attempt to describe the stocks and/or flows of students.

Since the majority of the models belong to the forecasting category, we find that the attributes to this category appear most frequently in the models. Here 32 models are concerned with enrolment forecasting and 26 models are concerned with the production of graduates. We have already seen, when we examined the subject-matter of the models, that, in terms of the head count of models, by far the simple majority of models (as many as 23) are primarily concerned with the subject of student flows. In terms of the frequency of the appearance of the attributes of models this also appears to be true. Eighteen models are concerned with forecasting new entrants and 15 models with success rates and/or drop-outs. Among the forecasting models, manpower availabilities

Table IV.4 SPECIFIC USES OF MODELS CROSS-CLASSIFIED BY TH

No. of model	Levels of education covered by the model	DESCRIPTIVE MODELS															FORECASTING				
		ONLY TO DESCRIBE:					TO EXPLAIN:										TO PROVIDE				
		The Total Educational System	Student Stocks and Flows	Budget Processes and Financial Systems	Teaching Staff and Other Personnel	Capital Stocks and Other Physical Facilities	Enrolments	Production of Graduates	Success Rates and/or Drop-outs	Costs and/or Expenditures	Teacher Requirements	Teacher Availabilities	Demand for Places	Availability of Places	Employment Choices	Relationships between Educational and Economic Variables	Enrolments	Production of Graduates	Success Rates and/or Drop-outs	New Entrants	Costs and/or Expenditures
1	Primary only																				1
2	Lower Secondary only						1														
5	Upper Secondary only						1		1				2		1		1			1	1
43	Higher [illegible]cation only				1			5	1	1			2			2	11	9	5	6	2
2	Primary and lower secondary																1				
20	Primary, lower and upper secondary						1		1		1		1				4	2	1	2	2
7	Lower and upper secondary												1	1			1	1	1	1	
4	Lower and upper secondary and higher education																2	3	1	2	
4	Upper secondary and higher education							1								2					
34	All educational levels		2													1	12	11	7	6	4
122	Total number / Frequency	-	2	-	1	-	3	6	3	1	1		6	1	1	5	32	26	15	18	10

EVEL OF EDUCATION COVERED BY MODELS

	ODELS						DECISION MODELS							SIMULATION MODELS															
	ORECASTS OF:						TO SOLVE FOR THE VALUES OF VARIABLES FOR:								TO DETERMINE THE EFFECTS OF:														
							GLOBAL DECISIONS		PARTIAL DECISIONS						ALTERNATIVE						UPON								
	Facility Requirements	Facility Availabilities	Demand for Places	Availability of Places	Manpower Requirements	Manpower Availabilities	Education Sector Only	Inter-Sectoral (Education, Manpower and/or Economy)	Allocation of Students	Allocation of Teachers	Allocation of Physical and/or Financial Resources	Optimal Size	Time-Phasing of Decisions	FOR TRAINING ONLY	Enrolments	Success Rates and/or Drop-outs	Student/Teacher Ratios	Teacher Salaries	Teaching Programmes and/or Schedules	Examination Procedures	Enrolments	Production of Graduates	Cost and/or Expenditures	Teacher Requirements	Teacher Availabilities	Facility Requirements	Facility Availabilities	Class Sizes	Manpower Availabilities
					1																								
			1																										
	1		1		2	4		1	2	1	7	1			3				4	1		1	4	3		4			
															1				1									1	
2	1					1					6						1				1								
1										1	1				2			1	2				1	2	1				
						1		1																					
								1																					
3			1	1	5	9		3				1		2	3	2	1	1	1		1	2	2	2	2	1			3
8	2	-	3	1	8	15	-	6	2	2	14	2	-	2	9	2	2	2	8	1	2	3	7	7	3	5	-	1	3

appear to be the concern of as many as 15 models. Only 10 models are concerned with forecasts of costs and/or expenditure.

If we now turn to decision models it appears that more models were concerned with problems of partial decisions rather than global decisions. It is surprising that, in terms of the purpose or use attributes of models, none of the 122 models was concerned with the global decisions of the education sector by itself. Despite the interests of the ministries of education in carrying out the model-building effort, it is strange that this effort has not been carried out directly for purposes of exclusively sectoral decision-making. As a result, it may be possible to contend that overall education planning in terms of the planning of the sector by itself has not used mathematical models of the kind which will permit an exclusive sectoral view and provide information on overall decisions. On the other hand, the recognition of the "openness" of the education sector in terms of its interrelationships with other sectors has resulted in global decision-models of an intersectoral kind, involving relationships between education, on the one hand, and manpower and/or economy, on the other. Among the models concerned with partial decisions, the most frequent use of models has been with the problems of allocation of physical and/or financial resources. We can count as many as fourteen models concerned with these types of decisions.

If we now look at the cross-classification of the frequency of uses of models with the level of education, we find that there has been a concentration of effort on certain levels of education rather than others. Again, if we look at the forecasting models we find that most of such models are concerned with all educational levels at the same time. The next most important group of forecasting models is those that are concerned with higher education alone. The third most important group of forecasting models is those concerned with primary and secondary education in its entirety. In each of these three groups of models we find the same pattern concerning the frequency of different uses as we found in all the models concerned with forecasting. That is, the majority of the models in each of these three groups is concerned with the forecasting of enrolments, followed by forecasts of the production of graduates, success rates and/or drop-outs and new entrants. Somewhat greater importance is attached to the forecasting of teacher requirements and teacher availabilities in the primary and secondary education level than elsewhere.

As regards decision models, we find a somewhat different pattern. Here the most frequent purpose attributable to models seems to be the allocation of physical and/or financial resources in higher education by itself. This same attribute is also almost as frequent in the case of primary and secondary education sectors.

Simulation models are more often concerned with either all education levels or with higher education alone. In each case, such models are concerned, by and large, with the determination of the effects of alternative patterns of enrolment upon, among other things, costs and/or expenditures and teacher requirements. Simulation techniques seem also to have been applied in the case of secondary education and the attributes of these applications do not seem to differ from those mentioned above.

As regards descriptive analytic models, we find that higher education again claims the majority of the purpose attributes of models. Here, as many as five models are concerned with the explanation of the production of graduates.

Part Two

SUBSTANTIVE DESCRIPTION

Chapter V

SUBJECT-MATTER

In this chapter we give a cross-section description of the subject matter of the mathematical models of the education sector using exclusively the replies to the questionnaire. In the first section we give the outline of a student flow model in general terms, since a majority of the models has incorporated this particular approach - even when their primary emphasis is on, say, resources rather than forecasting student enrolments. The presentation in the next chapter adheres to the subject-matter classification of models given in Chapter III. Here models are referred to individually in order to provide more detail than was possible in the aggregate analysis using model head-counts. The third section provides a description of the special class of models known as mathematical (linear) programming models. Model references are to their serial numbers, which permits the reader to obtain additional desired details from the annexes.

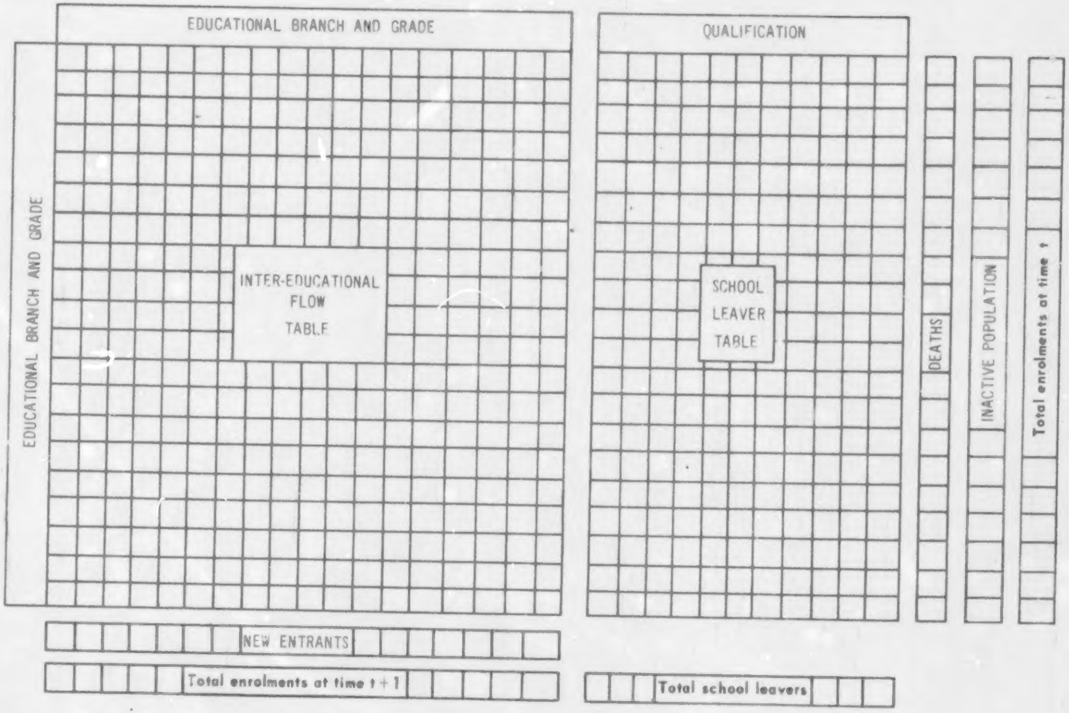
1. OUTLINE OF A STUDENT FLOW MODEL

Student Flow Table

A student flow table records the flow of all full-time students enrolled in each branch and grade of education at a given point in time (t) to any possible state one year later (time t+1). These possible states are:

a) A branch and grade of education, which may be different from, or identical to, that of the previous year;
b) The active labour force, differentiated by certain educational qualifications obtained while in the educational system;
c) Deaths;
d) The inactive population.

Table V.1 A STUDENT FLOW TABLE


EDUCATIONAL BRANCH AND GRADE
EDUCATIONAL BRANCH AND GRADE
INTER-EDUCATIONAL FLOW TABLE
QUALIFICATION
SCHOOL LEAVER TABLE
DEATHS
INACTIVE POPULATION
Total enrolments at time t
NEW ENTRANTS
Total enrolments at time t + 1
Total school leavers

A student flow table is shown in the Table V.1. The table is sub-divided into two smaller tables: the Inter-Educational Flow Table and the School Leaver Table. In addition, there are two rows at the bottom of the Inter-Educational Flow Table, one labelled New Entrants, the other labelled Total Enrolments at Time t+1. There is also a row at the bottom of the School Leaver Table labelled Total School Leavers. The columns at the right of the School Leaver Table pertain to student Deaths during the year, school leavers who enter the Inactive Population during the year, and Total Enrolments at time t. Each of the individual components of the student flow table is described separately below.

The Inter-Educational Flow Table

It is a square table consisting of one row and one column for each defined branch and grade of education. All students who were in the educational system at time t and are still there at time t+1 are recorded in this table. The row in which they are recorded represents their branch and grade at time t. The column in which they are recorded represents their branch and grade at time t+1.

In general, the diagonal will contain the number of repeaters in the corresponding branch and grade. Further, in most cases, the number of students who advance within the educational system will be found in the row representing their branch and grade at time t and the column representing the next grade in the same branch. This will not be true, however, for rows representing the last year of study in a branch since students can then advance to the first year of study in a higher level, or must leave the system in the case of terminal branches. There will, of course, be many zero entries in this table since many movements within the educational system are not possible. For example, one would not find students in primary school at time t who would be enrolled in higher education one year later.

The School Leaver Table

It contains one row for each defined branch and grade of education, and one column for each defined educational qualification. All students who were in the educational system at time t and have left education to become members of the labour force at time t+1 are recorded in this table. This table, therefore, can contain both dropouts as well as successful graduates who do not continue their education at a higher level the following year. The row in which the school-leavers are recorded represents the branch and grade of education in which they were enrolled at time t. The column in which they are recorded represents the qualification with which they leave the educational system. Dropouts from a branch of education are assigned a lower qualification than those students who successfully complete that branch of education. Upon leaving the school system, it is likely that a number of students will be unavailable for employment and will enter directly into the inactive population. This proportion of students is not recorded in the School Leaver Table but rather is treated separately.

The row labelled New Entrants contains the number of students in the educational system at time t+1. In general, the first entry will be the most significant since it records all the new students entering the first year of education. The row labelled Total Enrolments at Time t+1 contains the sum of each column in the Inter-Educational Flow Table plus the corresponding New Entrants. It, therefore, contains the total enrolments in each branch and grade of education at time t+1. The row labelled Total School Leavers contains the sum of each column in the School Leaver Table. It, therefore, contains the total number of school leavers who enter the labour force during the period t and t+1, for each defined educational qualification.

During the period between t and t+1, a certain percentage of the school age population enrolled at time t can be expected to die. These students are accounted for in the column labelled Deaths, according to the branch and grade in which they were enrolled at time t. The percentage depends upon the mortality of the age groups in the branch and grade, as well as the composition of the enrolment by sex. As mentioned previously, a certain proportion of the students enrolled at time t who leave the education system during the period between t and t+1 will be unavailable for employment and will enter directly into the inactive population. These students are accounted for in the column labelled Inactive Population, according to the branch and grade in which they were enrolled at time t. The number recorded depends upon the participation rates of the age groups and educational qualification achieved, in the branch and grade, as well as the composition of enrolment by sex. The column labelled Total Enrolments at Time t contains the sum of each row in the Inter-Educational Flow Table, plus the corresponding row in the School Leaver Table, plus the corresponding Deaths and Inactive Population entries. It contains the total enrolments in each branch and grade of education at time t.

A student flow table, as described above, is primarily an accounting device. As such, it serves to provide a consistent means of tracing the movements of students who are enrolled in each branch and grade of an educational system at a given point in time to a new state exactly one year later. From a statistical viewpoint, the construction of a student flow table is not necessarily a simple task. Ideally, an individualised data system, containing information about each student which is annually updated, would provide the best data base for constructing a student flow table. Even this system could not be exclusively limited to students, however, since we wish to differentiate among school leavers those who enter the labour force and those who become inactive. In an individualised data system, we would even wish to retain information about student deaths for at least one year in order completely to fill in the flow table.

Model based on Constancy Hypothesis

The base year transition coefficients matrix provides a framework for analysing demographic effects upon future enrolments and outputs. By assuming that all transition coefficients remain constant over the period under consideration and applying the base year transition matrix to subsequent enrolment populations for each period in the plan, it is possible to analyse the effects of purely demographic factors upon future educational enrolments and outputs. This procedure will be referred to as the application of the "constancy hypothesis". The reason that the constancy hypothesis permits the effects of demographic factors to be isolated for analysis is due to the fact that all other influences on the levels of educational enrolments and outputs presuppose a change in the values of at least two transition proportions. Since the constancy hypothesis assumes all transition proportions constant over the plan period, the results obtained by its application provide a solution which is independent of all non-demographic factors.

In the foregoing example, the enrolments in grades 1 and 2 at time t+1 are multiplied across each corresponding row of the base-year transitions table. The results are shown in the left-hand table in the first and second rows. In the third row, the new entrants are shown. This is an exogenously forecasted value and must be included for grade 1. The sum of the column totals in the results table gives the total enrolments in grades 1 and 2 during the first year of the plan period, as well as the number of school leavers during that year.

The process described above can be repeated for the next year of the plan period. In this case, the enrolments in grades 1 and 2 at time t+2 are inserted on the right-hand side and the base-year transition proportions are re-applied. Using this iterative procedure, the enrolments in grades 1 and 2 for each year of the plan period (including the target year) can be computed under the Constancy Hypothesis. Further, the school-leavers during the plan period (and the total over the plan period) can also be determined.

The application of the Constancy Hypothesis can be described in matrix algebraic form as follows:
Let:

T = Target year of the plan;

$S^{(t)}$ = Row vector of student enrolments in each branch and grade at the end of year t;

$E_N^{(t)}$ = Row vector of projected new entrants in year t;

$L^{(t)}$ = Row vector of school leavers during year t;

$T_E^{(0)}$ = Inter-educational transition coefficients matrix for the base year;

$T_L^{(0)}$ = School leaver transition coefficients matrix for the base year.

In the above, the matrix $T_E^{(0)}$ is the sub-matrix of the base year transition coefficients matrix pertaining to intereducational flows, and the matrix $T_L^{(0)}$ is the sub-matrix of the base year transition coefficients matrix pertaining to the flows of school leavers. Then, under the Constancy Hypothesis, the enrolments at the end of each year of the plan period and the school leavers during each year of the plan period are given in equations (1) and (2) below:

$$(1) \quad S^{(t)} = S^{(t-1)} \cdot T_E^{(0)} + E_N^{(t)} \qquad (t = 1,2,\ldots,T)$$

$$(2) \quad L^{(t)} = S^{(t-1)} \cdot T_L^{(0)} \qquad (t = 1,2,\ldots,T)$$

Having determined the impact of demography upon future enrolments and outputs, we must now consider how student behaviour and policy decisions for education can affect enrolments and output. To do this we merely need to recognise that any change in student behaviour or educational policy will reveal itself as a change in the values of transition coefficients over time. Examples of such changes can easily be cited. If students decide to remain in school rather than leave school to seek remunerative employment, the school leaver rate will decrease. If standards for promotion are changed as a matter of educational policy, the repeater rate is likely to change. If more places are created in universities it is likely that the proportion of students who move from secondary to higher education will rise. Such changes can be expressed in terms of changes in the transition coefficients over time. For this reason, a sub-model for education must incorporate not only demographic factors, but also the dynamic aspects of the change in the values of transition coefficients over time. The next section will deal with this subject.

Dynamic Transition Model

In order to consider the effects of changes in the values of transition coefficients upon enrolment levels and educational outputs over the plan period, it is first necessary to distinguish different types of coefficients. Four basic types of transition coefficients can be distinguished:

1. Repeater coefficients - pertain to those students enrolled in the same grade at times t and t+1;
2. Progressor coefficients - pertain to those students who advance to a higher grade (or branch) between t and t+1;
3. Drop-out coefficients - pertain to those students who leave the educational system between t and t+1 without a diploma from the branch in which they are enrolled at time t;
4. Graduate leaver coefficients - pertain to those students who successfully complete a branch of education between t and t+1 but do not continue to a higher branch.

Student mortality coefficients are not included above since they are not considered to be fixed by demographic factors. Further, inactivity coefficients are not included since they are considered as an exogenously determined proportion of the school leavers.

In applying dynamic transition matrices, the same computational procedure as that used under the Constancy Hypothesis is applied, with the following important difference. Whereas under the Constancy Hypothesis each subsequent enrolment vector is multiplied by the base-year transition coefficients matrix, the use of dynamic transition coefficients requires distinct transition coefficients matrices for each year in the plan period. Thus there will be a transition matrix pertaining to the first year of the plan, one pertaining to the second year, etc.

The application of dynamic transition matrices, described in matrix algebraic form, is as follows:

Let:

T = Target year of the plan;

$S^{(t)}$ = Row vector of student enrolments in each branch and grade at the end of year t;

$E_N^{(t)}$ = Row vector of projected new entrants in year t;

$L^{(t)}$ = Row vector of school leavers during year t;

$T_E^{(t)}$ = Inter-educational transition coefficients matrix which applies to year t;

$T_L^{(t)}$ = School leaver transition coefficients matrix which applies to year t.

The definition of the inter-educational transition matrix and the school leaver transition matrix as two sub-matrices of the overall transition matrix is the same here as was used in the algebraic form of the Constancy Hypothesis. Using dynamic transition matrices, the enrolments at the end of each year of the plan period and the school leavers during each year of the plan period are given by equations (3) and (4) below:

$$(3) \quad S^{(t)} = S^{(t-1)} \cdot T_E^{(t)} + E_N^{(t)} \qquad (t = 1,2,\ldots,T)$$

$$(4) \quad L^{(t)} = S^{(t-1)} \cdot T_L^{(t)} \qquad (t = 1,2,\ldots,T)$$

In using dynamic transition matrices, any given set of matrices applying to the plan period can be considered to represent some hypothesis of evolution for the educational system. The only restriction upon the values appearing in the transition matrix is that the coefficients must be non-negative and any row must sum to 1.0.

Target setting Model*

In the dynamic transition matrix formulation a different transition matrix applies to each year in the plan period. Of special interest is the target year transition matrix. Just as the base year transition matrix measures the dynamics of the educational system in terms of the rates of flow of students in that year, the target year transition matrix provides a means of translating specific planning targets into quantitative terms.

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* The numbers in brackets refer to the model number used to identify each model in the annexes.

To determine the implications for enrolments and outputs over the plan period of the targets chosen, dynamic transition matrices are used. The target year transition matrix reflects the planning goals decided upon by the Education Group. The transition matrices for the intermediate years in the plan period will be that set of matrices whose values increase at a constant annual rate from the base year to the target year values.

In mathematical notation, the procedure to be used is as follows:

Let:

$T^{(0)}$ = Base-year transition coefficients matrix;

$T^{(t)}$ = Target-year transition coefficients matrix;

n = Number of years in the plan period

A matrix, ΔT, of constant annual incremental changes in the coefficient values which will lead from the base year to the target year values in the plan period is given by:

$$\Delta_T = \frac{1}{n} (T^{(t)} - T^{(0)}).$$

In applying dynamic transition matrices, as previously described, the transition matrix applicable to year t in the plan period is, in this case, given by:

$$T^{(t)} = T^{(t-1)} + \Delta_T \quad (t = 1,2,\ldots,T)$$

The foregoing provides the basis for constructing a transition model to be used for evaluating educational targets in terms of their effects upon enrolments and outputs over the plan period. In addition, there are resource requirements implicit in the targets which must also be considered. The way in which the sub-model will treat resources will next be considered.

An interesting model (20) assuming just (a) stationarity and then (b) exponential growth, has been constructed for long-term analysis. The student enrolment equation for year t is:

$$(1)' \; S(t) = \frac{r'}{E} S\,(t-1) + E_N\,(t)$$

assuming enrolments $S(t)$ and entrants $E_N(t)$ constant, we have the "stationary solution":

$$S^*(t) = (I - r') E_N(t)$$

The use of the matrix $(I - r')^{-1}$ in the above equation is to determine average enrolment numbers required in each educational grade and branch for a given number of students entering the corresponding educational grade and branch each year (if the system is to remain in a stationary or self-reproducing state). The properties of such models and the various possibilities of introducing dynamic elements have been examined by T. Thonstad in Norway (20). The interpretation of the education system is in terms of a Markov chain model.

The foregoing use of transition matrix (68) is an extreme simplification to demonstrate the logic of the analysis rather than the possible practical application of the method. This illustration does not do justice to the analytical power and potential applicability of a large number of student flow models using transition matrices that have been surveyed. In addition, there are a number of different analytic forms employed by other models, which it is hoped will be described in subsequent studies and have been deliberately omitted from this presentation.

2. SUBJECT DESCRIPTION

Comprehensive Models of Education

From among the exclusively educational models we have separated out six "comprehensive" models of the education system. Probably the most well-documented model is that of Professor Stone in the United Kingdom (2), which attempts to describe and project the various components of the education system of England and Wales, in view of changing

a) demographic factors; and

b) transition proportions.

The model then examines the various implications of the above factors, as well as the expected changes in educational inputs. Using a somewhat eclectic approach, the London School of Economics Higher Education Research Unit (3) is currently working on different components of what is expected to be a comprehensive forecasting model of "the post-compulsory secondary level to higher education movements". Here, a number of separate "models", it is hoped, will eventually be linked together. The studies relevant to model building as a whole are: a student flow model, a manpower demand oriented project, an explanatory, or evaluative project, and a theoretical study in control theory. The United States Office of Education has developed a comprehensive methodology of making projections of the future development of the educational system (4). This model will be discussed in detail when we examine the forecasting role of models.

A generalised simulation model of the education system (6) is designed to tackle a wide variety of student flow problems incorporating restrictions on the capacity in different branches of education. It is not applied to a particular empirical situation but is open for use on a variety of problems:

a) data available;

b) problems tackled; and

c) structure of the system.

Such generalised models are of doubtful value in tackling concrete problems of comprehensive educational planning.

An attempt to project school expenditures with the aid of a comprehensive education model has been made in Germany at the Max Planck Institute (1). The model attempts to show the financial implications

a) of the growth of the educational system, due to autonomous demographic trends and the increase in the demand for education;

b) alternative "political measures" affecting education, which are indicated in terms of variations in student/teacher ratios, class sizes, special classes, etc.

The financial implications of alternative educational policies are compared with national income, and total public expenditures and revenue.

Finally, a PERT (Program Evaluation and Review Technique) model has been developed in Yugoslavia to implement the reform measures at the secondary educational level. PERT is a method of network analysis that takes into consideration the time element in planning and control of projects. (The effectiveness of this technique was demonstrated in 1958 when the Polaris Missile project was completed way ahead of schedule.) The Yugoslav model identifies 95 activities involved in the implementation of educational reform with associated time and cost estimates. The critical path is developed to determine the total lines and total cost of carrying out the reform of secondary education.

Student Flows

A number of student flow models as well as the comprehensive models use a transition matrix approach. In the Canadian model of school enrolments (11), the student flow concept is embodied in the use of transition ratios (though this does not seem to have been set down in the form of a transition matrix). In the student flow models of primary and secondary education in Germany (8) transition coefficients between different types of schools are regarded as policy parameters. The forecasting model of primary and secondary education in Iceland (18) uses a transition matrix (incorporating the output structure) with school grades as transition poles. The coefficents of the matrix are calculated from individualised data. The Irish model (16) also uses a standard transition matrix for all levels of education. Other examples of the use of transition matrices are in Canada (11) (12) and in Germany (7) among the models classified here as student flow models.

In the student forecasting model for Scotland (22), the flow concept is embodied in transition rates as far as graduates and leavers and new entrants in higher education are concerned, but a full transition matrix is not developed, and most of the forecasting parameters seem to be of the enrolment ratio type. Changes over time are measured in the proportion of pupils staying on at school, and the proportion of qualified school-leavers going to university. This latter proportion, immigration rates into the education system, length of courses, and the "relevance of present teacher training methods" are all considered as policy variables. There is more concern with the higher education sector than with any other, and enrolments in this sector are calculated as follows:

i) qualified school leavers, by level of qualification, are used as a proportion of the sum of all 16-18 year-old leavers. Time trends have been continued with some subjective trailing off;

ii) a weighted average (over two years - to avoid using freak figures from one year only) of the entry rate of qualified leavers into higher education.

These two proportions are multiplied into the numbers of school leavers to find the numbers entering each sector of higher education. Other smaller groups of entrants are estimated separately and added in here before the calculation of an "effective course length", done using a weighted average of the study-year-specific population.

A particularly interesting exercise is that carried out in the National Science Foundation of the United States, which demonstrates the application of cohort analysis technique for projecting enrolments in higher education (13). This will be discussed in greater detail below when the forecasting role of models is examined. The Belgian model for forecasting university enrolments (10) is based on past trends of participation rates and does not employ transition matrices.

Student Parameter Models

The higher education student flow model (31) uses the transition matrix where the transitions take place between one semester and the next. The basis for the numbers of students in their first semester of study is, for the most part, the output from a separate model (30). The rest of the input comes from German or foreign immigration into Baden-Württemberg. Policy variables are listed as follows: The proportion of immigrant Germans in higher education in Baden-Württemberg; the proportion of foreign immigrants in higher education in Baden-Württemberg; the distribution of all students over institutions (there is direct control over the numbers entering the pädagogische hochschulen - teacher training colleges - but entry to the other types of higher education - universities, higher engineering schools, and "culture" schools - is supposed to be free); and the distribution, within institutions, over as many as 12 subject-groups. Changes over time are measured in the immigrant proportions, transition and success rates, but the forecasting of these parameters is dependent in part on political decisions and plans, and the expectations of their effects.

Even though the purpose of the university student forecasting model of Germany (51) is to evaluate financial needs of higher education, the work is largely concerned with determinants of transition proportions. The number of study beginners is dependent in the first instance on age-group sizes, modified according to their progression through the gymnasium. The following coefficients are used:

i) The transition coefficient to the gymnasium (based on age-group enrolment). Two alternative assumptions are made. First, that this coefficient remains at its 1967 level of 22.8 per cent. The coefficient was approximately constant from 1952 to 1963, but has since risen to almost 23 per cent. The second assumption is that the coefficient would rise at about half the rate it has done in the last few years to 30 per cent by 1980-81. These are clearly not mechanical projections since the forecasts seem conditional on alternative likely policy decisions.

ii) The success rate at the gymnasium, i.e. the numbers of Abiturienten - pupils qualifying for higher education - compared with the numbers in the class of entry to the gymnasium. This was assumed constant at 63 per cent, on the basis of class-specific transition proportions. It may at first seem curious that this coefficient, perhaps less amenable to political influence than the first, should have no time-trend attached. This may be because either the trend really was zero, or not enough observations were available to establish a trend.

iii) The rate of study beginners, i.e. the number of study beginners compared with the numbers of immediate past Abiturienten. This has recently been more than 100 per cent because of late beginners and immigrants from other länder. The average of this ratio for 1961-67 was used (strictly speaking incorrect - the mean of the ratios is a biased estimator of the true mean; the ratio of the means should be used) and was thus projected as constant.

iv) The distribution over institutions of study beginners was also assumed constant. It does seem unlikely that all institutions would develop at the same rate, but without data there can be no firm basis for determining differing expansion rates.

v) Finally, length of study time was estimated using transitions between study-terms - a similar concept to ordinary transition coefficients, but one without a concept of "repeating" since the transitions are time-based only, and are not linked to an hierarchical classification of the educational system.

Intensive study of the influence of demographic and sociological variables on the rate and direction of movement of school pupils has been carried out at the Institut d'études démographiques in Paris (36). The model traces the movement of a cohort of pupils from primary through lower secondary into upper secondary schools. In another context, the factors affecting the flow of students from secondary into higher education and into the labour force are being examined in the United Kingdom by Professor Barnard of the Department of Mathematics at the University of Essex (37). He is attempting to explain subject and institutional choices of the students by taking into account school characteristics such as boarding arrangements, size, range of subjects offered, and counselling arrangements. The student characteristics include family size and background, success patterns, examination records and occupational and educational intentions. One study in the United States has even been able to quantify the pressure of military draft, in addition to other factors, such as tuition, income and aptitude, in the estimation for demand for higher education (33).

Teacher-demand and/or Supply Models

The structure of the models is quite similar. The demand for teachers is determined by two sets of factors:

i) demographical data, e.g. number of pupils enrolled by grade and field of study;
ii) organisation of education, e.g. class size, teaching time required per class, teaching load.

Important factors in the supply side are the present stock of teachers, withdrawals, qualified school leavers, and enrolment in teachers' training colleges. Most of the models give forecasts for the future supply of and demand for teachers, while a few simulate the effect on these two components of changing some important policy variables.

The problems of supply and demand for teachers have been tackled by a number of models in the United Kingdom. The Scottish Education Department (46) is constructing a teacher supply model which will forecast the supply of teachers by level and type of qualifications for the next 10-15 years. In the same department (47), a second model-building effort is in progress. This project deals with teacher requirements using stochastic simulation techniques.

Baden-Württemberg (39) has done some straightforward estimates of teacher requirements from projected flows of students in primary and secondary education. This study is disaggregated in great detail. In Germany, a model (38) has also been constructed for discovering whether the supply of teachers will meet the demand projected elsewhere. This model also analyses the effect of structural reforms of the educational system on the demand for and supply of teachers.

An example of teacher-cost oriented models (45) is that of Norway which deals with teacher inputs in terms of varying types of function of teachers. The changes in the structure and organisation of education and their repercussions on the need for teachers are linked with the effects of the regulations concerning methods of subsidisation by the central government of educational activities administered by local government authorities. The demand for teachers might, for instance, be different if the subsidies are given for the teachers' salaries instead of for capital expenditure.

A model has been constructed for Ireland (43) which analyses, among other things, the implications of administrative changes in the way teachers are paid on the supply of and demand for teachers.

A model for determining the size of the provincial grants to Quebec University, and the structure of academic salaries has been constructed in Canada (41).

A major problem in educational planning is to avoid disequilibria in the allocation of teachers to different types of education. This is examined in a model for optimising teacher utilisation in Germany (40).

For Italy, a model (44) has been developed which, after having measured the shortage of teachers in the Italian universities, proposes an optimal allocation of the teachers in these institutions.

Resource Models: each of these is given below.

A simple model of the financial needs for higher education has been worked out by the Gruppe Bildungsplanung in Dusseldorf, Germany (51). General cost models for education have been constructed, both in the Norwegian Research Council (63) and in the

Department of Research and Planning of the Norwegian Ministry of Education (64) (65). A similar method has been applied to the Turkish situation (67).

The problem of student grants, college subsidies and other assistance has been tackled by simple models in a number of countries, such as Canada (Quebec and Ontario) (56) (55), and the Scottish Education Department (66). The Quebec model attempts to determine provincial grants to local school districts in such a way as to provide minimum educational facilities for all and to equalise the financial burden among districts. The Ontario model has devised formulas for provincial capital and current grants to 14 universities. Considerations of adequacy, supplemental assistance to "emerging" universities, and allowance for autonomy are taken into account.

The two stated purposes of the Scottish model (66) are:

a) to relate government assistance for education to local authorities to the needs and resources of each of the local authorities by using criteria for equalising the burden on each community;

b) to determine amounts for new construction in a way that will provide approximately equal school facilities across the country within the constraint of total construction resources.

Models dealing with the location of schools and education departments among various regions within a country have also been included here. The Belgian model (52) deals with the location of new industrial high schools for engineering using linear programming to minimise transport costs. Models of the location of schools in the counties of the province of Ontario in Canada (53) (54) take into account budgetary implications of revisions in the county school district system. The distance between students' homes and schools is an important determinant in the location of secondary school facilities in the French model (60), which is kept up to date at the Ministry of Education. The Irish model (61) considers the best way to allocate departments to colleges located at separate sites.

A number of these resource models utilise the linear programming technique. We shall describe a few cases in greater detail below.

Externally-Linked Models

A straightforward manpower approach is evidenced in the Canadian model (89) which takes future manpower requirements arising from the growth of the Canadian economy and attempts to determine consistent education, training, employment and career guidance, as well as immigration policies. The manpower demand model of France (91) takes the Fifth Plan projections of total employment by industry and the related occupational composition. This, in turn, is converted into the needs for graduates of the education system by level and type. A long-term forecasting model of the demand and supply of graduates from higher education by type qualification is tackled by the Italian model (92). A number of Japanese models (97) (98) (99) in the government agencies have concentrated on the links between the output of the education system and the manpower requirements of industry disaggregated in a number of ways. The Planning Division of the Ministry of Finance in Norway (93) has calculated the long-range future demand for educated labour up to 1990.

A sufficient number of examples has now been given to indicate the wide variety of countries using very similar approaches in this type of model. In the case where an attempt is made to cover the economy and the manpower system together with the education system in a consistent manner, we have treated such models as "comprehensive externally-linked" models. The purpose of the theoretical model in Austria (68) is to investigate the possibility of representing the educational system as a self-adaptive process, adapting to continuous manpower projections in varying time spans, and allowing the short-term influences to dominate the forecasts. There are other general econometric-type models using the Leontief input/output analysis. This is to be found in Canada (69), Norway (74), Portugal (78) and in a special model constructed within the Secretariat for training purposes (82). A general optimisation model of the economy in the education system has been worked out by the French group (CEPREMAP) (72). The three models of the Netherlands, short-term (75), medium-term (76) and long-term (77) are comprehensive in nature, linking the education model with the econometric model of the Centraal Planbureau.

With the exception of the Netherlands, none of these global models seems to have been integrated into policy-making within the governments. They appear to be of limited use for short-run decision making. From a long-run perspective, they provide interesting illustrative insights and, at this stage of their development, must be regarded as highly experimental. Apart from that, it has not yet been proved that large-scale "global" models can really be of any great validity in view of our limited knowledge of how the multi-facetted system works.

To our list of the externally-linked models should be added returns to education covered by the survey. These are largely designed to determine the demand for education of an individual in terms of his attempt to maximise the discounted sum of his expected lifetime income stream (104). All these models are of a descriptive nature and their practical use in, say, attempting to explain the number of applicants for admission to educational institutions has not yet been realised.

Institutional Models

The institutional models may roughly be divided into three groups according to subject matter. None of the groups, however, can be regarded as homogeneous.

The models in the first group may be called capacity models. These are probably the simplest ones as far as the number of variables and the mathematical complexity are concerned. Their objectives are, in general, to answer questions of the following type: how many students can be taught, given certain limits on the resources available; or, what is the influence of changes in a university admission system on the stock of students? Models constructed for answering questions of the first type have been built in Germany (105), (106) while a model dealing with problems of the second type has been built in Belgium (109). Another type of problem in this connection is to make forecasts for the future student enrolment and output from a university and to compare those forecasts with forecasts of the future demand for graduates. The question in this case is whether the capacity of the university is sufficient to meet the stipulated demand. A model of this type has been constructed for Schleswig Holstein (107).

The second group mainly consists of models which may be called resource requirement models. Their objectives are, for instance, to estimate:

a) the resource requirements to sustain a given teaching programme;
b) the resource requirements of alternative teaching programmes;

c) current costs of an institution of higher education;
d) investment costs for new universities or expansion of existing ones.

A number of models of the first type have been developed and used for different institutions of higher education in Canada (110), (111). The models accept descriptions of the teaching programmes and produce resource requirements to sustain these programmes. Different sub-models are used for computing the requirements for the different types of resources. A linear programming model is, for instance, used for computing the staff requirements for the Ontario Medical Schools. This model produces statements of the number of staff required to meet a given set of constraints. Among these constraints are a given training programme, staff policy objectives of the departments, and staff time profiles. A number of objective functions may be used, including minimising the staff numbers or the salary costs.

Models used for universities consisting of different departments or faculties must take into account that the teaching within the different faculties is given in groups of different size. If the input of a teacher's services is measured by his teaching obligations, it is also necessary to take into account the fact that the teaching obligations are different for the different types of teachers.

A model developed in Norway includes as teaching obligations the number of hours required for the preparation of the lectures (117). The objective is to identify the input of teacher services not only into education, but also into research. The argument for doing so is that the aim of a university is not only to be a teaching institution, but also to be a research institution. Because of this, a lot of the resources used by a university are spent on research and not on teaching only. Among the costs this model includes the input of study-hours by the students. The argument is that since this time from a university's point of view is not connected with any costs, it is likely to use too small an input of teaching hours and too much student time.

This model also gives a framework for estimation of the investment which a student represents when he leaves the university. In so doing, the "income foregone" by the student during his education is included. This brings in an element which is to some extent arbitrary. There is no generally accepted method for measuring income foregone. Furthermore, it is questionable whether this should be included in measurement of costs. Measurement of costs is as follows: the distinction between input of student time, on the one hand, and use of buildings, equipment and teachers time, on the other hand, is not one of theoretical principle; it is one of statistical expediency. The costs of buildings and use of equipment are measured directly by what is actually put in, while the income foregone is measured by what could have been earned by the student had he not entered the institution. But the actual money outlays on teachers, plant and equipment are themselves only estimates of the goods and services foregone for other purposes. According to this, there is no difference, in principle, between these two cost components, and the use of the concept of income foregone introduces an element of inconsistency.

Since the salaries constitute a major portion of the costs of higher education, information about the future trend of academic salaries is needed for the analysis of future costs of higher education. A model on "The Economics of Academic Staff" has been undertaken in Canada (112). The objectives of this project have been, among others, to estimate the state of the markets for various kinds of academic staff during the next 15 years. A model of the labour market for university teachers has been built.

Another aspect is to examine the possible economies of scale by increasing the enrolment to an institution. This was done for a teachers' training college in Denmark (113) by establishing a quantitative relationship between the total number of students admitted per year and the demand for teaching hours and room per student. It was found that within a certain range this demand was decreasing.

Another way of measuring the economies of scale would be to have several universities with exactly the same structure, but with a varying number of students. An analysis of this kind has been attempted in Norway (116) for the University of Oslo and the University of Bergen. These two universities have a quite similar structure, but the former has about four times as many students as the latter. According to this analysis, the average cost per student would have been about 17 per cent lower in Bergen if this university had had the same number of students as the University of Oslo. It is of course impossible to draw any definite conclusions from only two observations, but the result might give an indication of the direction in which the average cost per student will change when the student stock increases. Answers to questions of this kind can be of great value when decisions have to be made whether a new university should be built or an old one should be enlarged in order to increase the number of student places.

The third group consists of models which try to measure the productivity of an educational institution or to evaluate the extent to which the institution fulfills its objective. In order to do so, the objectives of the institution have to be defined explicitly. Many individuals and groups influence the formulation of objectives in higher education systems: the administration, the students, the public, the press, etc. Most of these influences are implicit and very hard to express explicitly and to quantify. This does not, however, make them less important. It just complicates the evaluation of the system and increases the probability of inconsistency and conflict among objectives.

A project entitled "Objectives, Success Measurement and Feedback in Higher Educational Systems" (112) has been undertaken in Canada. The purposes of this project are, among others, to explain how objectives are formulated and articulated in higher educational institutions and to evaluate the way in which they are formulated. It further seeks to ascertain the criteria by which success is measured in higher educational systems and to evaluate these criteria.

As a measurement of the productivity of an institution of higher education in the United States (122), an institutional model uses the percentage of graduates who go on to graduate school and receive doctorates. This measurement is related to various types of input variables. A Dutch model (119) uses as a measurement the number of students who graduate from the institution. A more ambitious approach is to establish a general framework for incorporating all the factors affecting the quantity and quality of the outputs of the educational system. A model following these lines has been developed in the United Kingdom (120).

Still another aspect is to try to establish a quantitative relationship between the patterns of courses offered by an institution and certain characteristics of the institution (e.g. size, number of teachers, number of teaching hours, etc.). The aim is to explain the extent to which each characteristic of the institution explains the observed patterns of courses offered. A model of this kind has been developed in Ireland (115).

The problem of designing better management tools for university administrators may be said to be one of developing better information systems; decisions concerning university planning and budgeting require information. A project whose objective is to formulate integrated university information systems to meet the needs of decision-makers (112) has been undertaken in Canada. This work is in its initial phase.

3. MATHEMATICAL PROGRAMMING

When the model was described as a mathematical programming model, a special set of questions was posed dealing with problems specific to such models. For example, information was obtained on the formulation of the preference function, the quantity being maximised, the type of constraints, plus the algorithm used to obtain the solution. Finally, the respondents provided information on whether the dual was calculated for the programming model and the interpretation of the shadow prices obtained from this calculation.

The linear programming technique has been employed in a dozen different models and in 8 countries. The first type of application of this technique is to the problem of optimal location of schools in Belgium (52), Ireland (61) and Canada (54). An optimal location of schools and universities, within a given area, may be considered optimal in the sense of minimising students' travelling time, or distance, or the cost of transport. Here, the notion of an optimum can be easily accepted, because the objective of such a problem is well recognised. Linear programming in such cases seems to be an efficient tool for decision-making.

The second case of linear programming applications presents greater difficulty in its application and use. Here, the preference function is not obvious at all and needs justification. The Norwegian model (21) tries to determine the "optimal allocation" of student entrants among the different types of post-secondary education, given that a certain required output is fixed exogenously; or, alternatively, to minimise the total study time of all graduates, given the same desired output. In the Austrian model (68) the cost minimisation is associated with a unit change in the value of a transition coefficient, when the coefficients are changed in order to satisfy manpower demands. The German model (40) attempts to optimise the utilisation of available teaching time. Given the number of students in secondary education in different types of school, the model tries to balance the supply with the demand, with given constraints on total teaching time, class sizes, various details on transfer of teaching staff, in and out from the outside world, in-service training and so on. The global model of Golladay (71) tries several preference functions within the same feasibility space (e.g. maximising GNP, minimising the employment of foreign workers, maximising the consumption, minimising unemployment). The French model tries to maximise the social preference function which concerns consumption during the time-period under consideration, capital stock and qualified manpower in the target time-period (72).

It is interesting to examine and compare two full-fledged programming models of the education system linked externally to the manpower and the economic systems (71), (72). Both models are designed for decision-making and the formulation of educational policy. Each model, however, represents a different approach and follows a different formulation. In their broad outlines the models are very similar. In table V.2 we have compared the distinguishing features of each of the two models.

Rather than examine the full set of constraints of each of the two models, we shall confine our attention only to those constraints that are concerned with the flow of students within the education system. In the Bénard model (72) the student flows are expressed as follows:

$$\underbrace{S_3(t)}_{\begin{array}{l}\text{Education}\\ \text{enrolment}\\ \text{vector with}\\ \text{elements}\\ S_h(t)\text{ at}\\ \text{time t and}\\ \text{in educational}\\ \text{level h}\end{array}} - \underbrace{\left[\hat{\rho}_3\right]}_{\begin{array}{l}\text{Diagonal}\\ \text{matrix of repeater}\\ \text{coefficients } P_h\\ \text{for educational}\\ \text{level h}\end{array}} \left[I - \underbrace{\hat{\delta}_3}_{\begin{array}{l}\text{Diagonal matrix}\\ \text{of attrition}\\ \text{coefficients } S_h\end{array}}\right] S_3(t-1) + \underbrace{\left[P_3\right]}_{\begin{array}{l}\text{Matrix}\\ \text{of}\\ \text{negative}\\ \text{incidence}\\ \text{between}\\ \text{educational}\\ \text{levels}\\ \text{(element -1 or 0)}\end{array}} \underbrace{Y_3(t)}_{\begin{array}{l}\text{transition}\\ \text{flow of}\\ \text{school popu-}\\ \text{lation from}\\ \text{one educat-}\\ \text{ional level}\\ \text{to another}\end{array}}$$

$$\leq \underbrace{J_3(t)}_{\begin{array}{l}\text{Vector of new entrants to the}\\ \text{education system with elements } j_h(t)\end{array}}$$

Table V.2

COMPARISON OF FEATURES OF BÉNARD AND GOLLADAY MODELS

Model / Features	Bénard (72)	Golladay (71)
1. Affiliation of Model-builder	Governmental Organisation	University
2. Application	France (test model)	Morocco (policy model)
3. Scope	Education-economy simultaneous optimisation	Education-economy simultaneous optimisation
4. Orientation	Emphasis on manpower approach	Emphasis on cost-benefit analysis
5. Preference Function	Maximises the sum of the present value of consumption and the productive capacity after the plan period	Seven functions including maximisation of the sum of the discounted value of GNP.
6. Structure and subject treatment	Occupational shift matrix to take into account job upgrading	Similar treatment: on-the-job training as alternate method of skill formation.
	"Closed" system, i.e. no extra-territorial flow of humans.	"Open" system with foreign studies and foreign teachers.
	Fixed and deterministic education-occupation link, i.e. fixed skill-output and education occupation coefficients	Flexible educational requirements for occupational categories. Manpower requirements satisfied by alternative mixes of education and job experiences.
	No substitution possible in the production sector of the economy	Choice of techniques permitted
7. Mathematical procedure	Multi-period linear programming technique	Dynamic linear programming technique

In order to ensure that the model will not provide for enrolments below some socially or politically permissible minimum levels, Bénard introduces the following constraint :

$$[\hat{\pi}_3] \; [I - \hat{\rho}_3] \; [I - \hat{\delta}_3] \; S_3(t-1) - [M_3] \, Y'_3(t) \leq 0$$

Diagonal matrix minimum transition rates between educational levels with elements πhh

Matrix of positive incidence between educational levels (element +1 or 0)

To study the effects of the various policies, Bénard suggests working out parameters for the value of the matrix of transition rates.

The analytic machinery for handling the student flow system is not very different on the Golladay model (71). He introduces two constraints:

(1) Flow of students graduating:

$$[I - d][E_t] = [L]^{-1}[W_t]\,\hat{i} + [r]^{-1}[E_{t-1}] + [L]^{-1}[T_t]$$

Vector of enrolments in each level of education system

Matrix of weak-force assignment variables

Matrix of teacher force assignment variables

Diagonal matrix of drop-out ratio

Diagonal matrix of continuation probabilities student-force participation ratio

Diagonal matrix of labour force participation ratio specific to each educational level

($\hat{i}$ = vector of ones to obtain summations)

Here the output of the education system is either retained as teachers, or as continuing students, or delivered as non-teaching work force.

(2) Flow of student dropouts:

$$\left[d\right]\left[E_t\right] = \left[\Sigma\right]^{-1}\left[Z_t\right]\hat{i}$$

Diagonal matrix of
labour force population ratio
specific to dropouts of each level
of education system

Work force assignment
variables for dropouts
entering labour force

(3) Population flow:

$$P_t^o \geq L_{11}\,W_{ot} + r_{11}\,E_{1t}$$

Labour
force

Primary schools

Exogenously
specified
population of
school entry age
during period t

School age illiterate population
assigned to

These two models differ rather sharply in their treatment of the link between education and the economic system, on the one hand, and between education and the manpower system, on the other. Both models view the education system as supplying the economy with manpower. The manpower requirements of the economy affect the decisions concerning allocations of graduates to (a) continuation in education, (b) teaching labour force and (c) non-teaching labour force. The Bénard model imposes rigid training requirements on the students. The Golladay model, however, permits substitution of educational backgrounds within each occupational group. The latter model seems more realistic and therefore more useful for policy-making.

Professor Bénard's conclusion about his own model (and this is generally true for this class of models) is that, "There can be no question of this model, any more than any other of the same kind, mechanically determining the decisions of public administration in matters concerning the economy and education".

In all the cases of programming models, the biggest problem is to quantify the preference function, especially when it is a question of marginal utility (Bénard). This difficulty has important consequences when it is known that a small variation in one or more of the coefficients of the preference function can generate a sharp reaction in the optimal solution. There is then, the necessity of doing sensitivity analysis which is only rarely carried out. Only one case is reported. The determination of a whole "optimal" domain, comprising the set of different optimal solutions obtained as a result of the sensitivity analysis study, would seem to be an indispensable step before effective use can be made of results.

Chapter VI

TECHNICAL ASPECTS

In this chapter we describe the forecasting procedures used in mathematical models of education. We then illustrate a theoretical algebraic model using a simultaneous equation approach. Finally, we discuss some problems of parameter estimation.

In the first instance we shall give seven examples of student forecasting procedures. These examples may be considered as the best current practice in the field. The description of the forecasting models provides a context for discussing some of the technical aspects of models. It will be recalled that the predominant purpose of mathematical models of education surveys has been to make forecasts of the variables of the education sector.

The broad conclusion that was drawn from aggregate review of the models was that the role of model building in education has been unduly restricted to making forecasts with an emphasis on long-term time horizons.

1. EXAMPLES OF FORECASTING

Example 1

In Forecasting University Enrolments in Belgium (10) all forecasts are based entirely on observed past trends. They are long-term forecasts, by university, by sex and by faculty: There are four alternative sets of equations.

Let: N_t = total number of enrolled students at time t.

Non-subscripted t = time trend.

Then,

i) $N_t = a + bt$: the annual increase in the number of students is constant.

ii) $N_t = ae^{bt}$: the proportional annual increase in the number of students is constant.

Neither of these first two formulations uses the number of persons qualified to enter university as a starting point for their projections; nor do they consider the size of the age group from which university students are generally drawn as a relevant factor. That is, the demographic element is ignored and the number of students depends only on the time trend.

If we now redefine N_t as a weighted sum of age-specific total populations (weighted according to age-group enrolment ratios) and define P_t as the total age-group population, then:

iii) $\frac{N_t}{P_t} = a + bt$: the annual increase in the weighted sum of age specific student enrolment rates is constant.

The projected proportions are then multiplied by the future age-group population size, i.e. we have $N_t = a.P_t + bt.P_t$. A few points need to be made here. First, though it is probably the most widely used method of doing enrolment projections, there are some theoretical objections to forecasting proportions using least squares techniques and then multiplying by some future, elsewhere forecast population size. This has been brought out by E. Meulepas in "Critical Survey of the Forecasting Methods in Belgian University Population Forecasts". Tijdschrift voor Economie, No. 1, 1966, pp. 68-104 (in Dutch; reprinted in English, by the Centrum voor Economische Studient, Catholic University of Louvain).

Secondly, multiplying the projected proportion by the future age-group population assumes that the age distribution of the future population is identical with that used in the projected proporti[illegible] This is unlikely to be so, particularly when we are considering the generation born just after the war when demographic trends were erratic.

The fourth equation has the following form:

iv) $N_t = a + bt + cP_t$ [N_t and P_t as in (iii)]: the annual increase in the weighted sum of the age specific total population is a linear function of time and age group population size.

Here we see the demographic and time elements are accounted for separately, but the formulation still has the weighting problem of (iii). Meulepas suggests using N_t as defined in (i) and (ii) in an equation like (iv). This is certainly sounder than (iv) as it stands.

It should be noted that the first and last points made about equation (iii) can be restated wherever a proportion is forecast. This will occur frequently in other models. Another point of perhaps more general interest is that no flow concept is involved in the model; only stocks are forecast using enrolment rates rather than transition proportions.

Example 2

The Long-term Forecasting Model for the Education System in the Netherlands (77) forecasts enrolments at ten year intervals up to 1999. All the forecasting is based on age specific enrolment rates, involving time series of these rates dating back to 1850. It should be pointed out that the results are not expected to be precise, accurate forecasts of future enrolments, but rough indicators of the orders of magnitude to be expected in the future.

Four enrolment rates are used, all of which are considered as policy parameters. They are:

$$P_1 = \frac{\text{Infant Enrolments}}{\text{Population aged 3-5}} \qquad P_2 = \frac{\text{Elementary Enrolments}}{\text{Population aged 6-14}}$$

$$P_3 = \frac{\text{Secondary Enrolments}}{\text{Population aged 12-25}} \qquad P_4 = \frac{\text{"Scientific Education" Enrolments}}{\text{Population aged 18-25}}$$

It seems fair to assume that "Scientific Education" includes all branches of higher education.

Each of the flow parameters is then forecast (using straightforward projection or some type of constrained forecast). The future age group sizes are known from population projections and these are multiplied into the appropriate proportions to give the enrolments. One fact will be noticed immediately - because of the extreme long-term nature of these educational projections they are more than usually dependent on reasonably accurate population projections. If, as has so often happened in the past, the demographers cannot get their projections right, the educational planners can hardly be blamed if their forecasts go wrong.

Example 3

A Student Forecasting Model, continuing through into first employment has been developed in Germany (83). All full-time education is included in the model, which forecasts up to 1975. The number of school beginners is based on the number of six and seven year olds, but once into the system, links between different levels and branches are set up using an ordinary transition matrix. Future values of individual transition coefficients are set partly as trend variables (i.e. ordinary extrapolation), and partly as educational-political variables. This is confirmed insofar as policy variables are a) school transition coefficients, b) university entrants.

Late entrants to various parts of the system are calculated independently by "trend extrapolation", though whether the trend is in absolute numbers, or in the proportion of total entrants, or something else, is not clear. Presumably, once the late entrants have entered, they are amalgamated with the other data. The projection of leavers from universities and engineering schools is done by examining each study year for several years to find the proportion of an original entry cohort still studying in each successive semester and to discover how these proportions are changing over time. A similar procedure is used to calculate the timing of entry to vocational schools. An important part of the study will be to show the link between output by qualification and first occupation; but as yet there is no data on this transfer.

Example 4

In the United States projections are made of enrolments at all levels, of high school graduates and of degrees by level field, at the United States Office of Education (4). The projections of the number of children entering the first three grades of public education, high school graduates, first-time and all higher education enrolments and degrees by level, are based directly on population as shown below:

Kindergarten)
Grade 1) Population aged 5, 6 and 7 for each grade.
Grade 2)
High school graduates: population aged 18
First-time college enrolments: population aged 18
All college enrolments: population aged 18-21.

The lags between different degree productions were assumed to be as follows: Bachelors: 4 years after college entry; Masters: another 2 years; Doctors: another 3 years; and the projection of degree output was based on the relevant age-group population, assuming the chosen time-lag, fitting the entrance of the student into college. Enrolments in grades 3-12 of public education are based on retention rates; degrees by field are based on the distribution over the last ten years. Everything else is based on enrolments. In almost every case, a straight-line regression was attempted with time as the independent variable.

Several points need to be made. First, it should be noted that enrolment in each of the first three grades of public education is based on the same population. Thereafter transition ratios are used, but these could not all be projected linearly since they have risen too rapidly recently, so an asymptotic equation with the limit at 100 per cent was used, except for instances where there is considerable transfer from the private to the public field. It seems curious that the projection of high school graduates should be based on the age-g[illegible]ze rather than the enrolment in the last grade of school. Si[illegible]ly, why should first-time entry to college be based on the same age-group rather than the number of high school graduates? For projecting the output from higher education, by type of degree, it is perhaps more practical to use age group sizes in view of the greater flexibility of the structure of the higher education system but, again, in view of this flexibility, it seems impractical to stick to single-year age-groups only for predicting Bachelors' degrees (22 years); Masters' degrees (24 years) and Doctorates (27 years). Whether these or any other projections would have been more accurate (in terms of the proportion of the variants accounted for) using a different formulation we do not know, since in no instance is R^2 given with the regression equation.

Furthermore, where no consistent series was available, or data were too irregular, a constant term based on the last observation or an average of the last two or three years was used. In addition, "where the fitted line lies considerably above or below the last observed point .. to give face validity to the projections, the fitted line was used only to establish the last point of the projection period and a new line was drawn through the last observed point to the end point of the projection period. When any one of a group of component curves is so adjusted, they all are." There is no indication of any objective assessment of the necessary magnitude of the discrepancy before this procedure takes place; there is no indication of any attempt to examine the last observation to see if it was a freak result, e.g. by re-doing the regression, omitting the last value and examining - once again - the last point and the respective R^2 for the two equations; there is no indication that any curve other than a straight line was tried and tested for a better fit, and though it may be advantageous for a group of component curves all to be projected linearly, since the ratios can then be added, the very proper wish for computational simplicity should not be allowed to override a non-linear equation giving a closer fit. We cannot be sure that this is not the case. Once again, it is said that an independent curve was adjusted only "when the discrepancy was serious", without indication of the measure of seriousness.

Example 5

In the United States' model, entitled Demonstration of the Application of Cohort Analysis Technique for Forecasting Enrolment and Degree Data (13), the forecasts are made for university level only, up to 1984. The author has tried to include as many intermediate steps into the projections as possible. Assumptions made affecting the future development of the system are as follows:

i) trends in social behaviour will follow recent observed experience;

ii) graduate studies are generally in the same field as undergraduate studies;

iii) the rise in junior college enrolment has no great effect on graduation rates, or on postgraduate enrolment;

iv) there will be no fundamental change in the structure of higher education;

v) there will be no catastrophic change in economic and social patterns;

vi) government support for students will follow past trends and student costs will not alter so much as to change their present evaluation in deciding to go to college or not.

Except for (iii), which is possibly the point most in flux at the moment, these are normal assumptions which have been set down explicitly.

The steps involved in making the projections are as follows:

i) Determined the total entry rates into college for 18 year olds from each birth year (for men, assumed to rise at 0.5 per cent per annum, simple interest; for women, the rise is 1 per cent. Both of these more or less continue present trends).

ii) Determined the distribution over a number of years of the entry of the 18 year-old cohort to college (e.g. for men, of one 18 year-old cohort, 15 per cent enter at 18, 55 per cent at 19, 15 per cent at 20, 4 per cent at 21, 3 per cent at each of 22, 23 and 24 and the final 2 per cent at 25).

iii) Determined from (i) and (ii), the total entries into college each academic year from all relevant cohorts (e.g. in 1960, 15 per cent of the 1960 18 year-old cohort, plus 55 per cent of the 1959 18 year-old cohort entering at 19, plus 15 per cent of the 1958 18 year-old cohort entering at 20 and so on).

iv) Determined Bachelors' level graduation rates from college for each entering cohort. This was constant (for males) at 57 per cent from 1957-1966 and was thus projected as constant.

This is unfortunately erroneous: the graduation rate of 57 per cent is calculated from the number of graduates as a percentage of entrants four years earlier. This will clearly not comprise only those who entered college four years previously, but a distribution from earlier years as well. That this is recognised by the author is evident from step (v). If it were possible to discover the year of entry of each graduate, step (iv) could be abandoned since the data would be available in the form in which it is needed after step (v).

v) Determined the distribution over a number of years of graduation of the graduates of (iv). The permitted distribution is between four and eight years and for men is as follows: 70 per cent, 10 per cent, 10 per cent, 5 per cent. 5 per cent; i.e. of the entry cohort of year t, 70 per cent will graduate in four years, 10 per cent in five years and so on.

vi) Determined the total graduation per year from (iv) and (v).

vii) Determined the entry rates into graduate training for graduates from each year (e.g. of 1957 graduates, x per cent go to graduate school).

This procedure carries the same potential flow as step (iv), with the data simply not being available and a spurious graduation year specific entry being calculated.

viii) Determined the distribution over a number of years of the patterns of new entrants to college.

ix) Determined the total new entry to college by college year, from (vii) and (viii).

x) Determined the pattern of retention in enrolment for higher degrees (fixed for males studying science at 100 per cent, 75 per cent, 60 per cent, 45 per cent, 30 per cent, 15 per cent, 10 per cent, 5 per cent).

xi) Determined the total enrolment in graduate education each year from (x).

xii) Determined the proportion of each year's entries into graduate education obtaining doctorate degrees.

Step (xii) suffers, potentially, from the same drawbacks as steps (iv) and (vii). In addition, there is no explicit recognition of the Master's degree and of persons who leave with this as their highest qualification. If the model is meant only to deal with Ph.D.s amongst higher degrees, this omission is of no importance, provided it is recognised that not all those who leave graduate education without a Ph.D. are drop-outs.

xiii) Determined the pattern of receipt of doctorates for each year's entries into graduate education.

xiv) Determined total number of doctorates per year from (xii) and (xiii).

On the pure forecasting front, the care with which the theory of this model has been developed makes it one of the best examples in the survey. It is indeed a pity that practical considerations have forced the methodological error mentioned above; even so, it should still be possible to avoid this mistake by telescoping stages (iv) and (v), (vii) and (viii) and (xii) and (xiii).

Example 6

The United Kingdom model of Student Flow with an Emphasis on Post-compulsory and Higher Education (3), particularly upper secondary and the transfer to higher. A transition matrix is the tool used for forecasting and this is used for making long-term projections. In an attempt to forecast more accurately the various trends of the 15-19 year old group, three alternative methodologies have been developed:

a) i) A calculation of the age group likely to attempt "O" level. This is probably a weighted average of different age groups.

ii) A calculation of the proportion of (i) taking six or more "O" levels. This assumes that only those pupils taking six or more "O" levels are to be reckoned as potential university entrants.

iii) A calculation of the proportion of (ii) passing an "A" level course. This is a curious step. Whereas the "O" level calculations were done in two steps up to the point of sitting for the examination, the jump is from there (no mention of a proportion passing "O" levels or of another proportion sitting "A" levels, or two or more "A" levels) to the proportion passing an "A" level course. We must also assume there is a time lag (two years?) between the proportions of (ii) and (iii).

iv) The proportion of (iii) passing two or more "A" levels.

The proportions (ii), (iii) and (iv) are multiplied together and then multiplied by (i) to find the numbers of pupils qualified for university entrance out of an initial potential "O" level cohort.

b) i) The numbers in school attempting one or more "O" levels.
ii))
iii)) as in (a)
iv))

The remarks made under (a) concerning (ii), (iii) and (iv) still stand. It is worth noting regarding (b) (i) that we must assume the numbers are not a result of an extrapolation of "O" level entrants but are at least partly dependent on the size of the age-group likely to attempt "O" level. Otherwise, there is no demographic element allowed for.

c) i) The size of the age group likely to attempt "A" level. We have immediately a radical departure from methods (a) and (b), both of which depended in the first instance on potential or actual "O" level entry.
ii) The proportion of (i) in the first year sixth form.
iii) The proportion of (ii) continuing to the second year sixth form.
iv) The proportion of (iii) passing "A" levels.

In all cases, the proportions may or may not be themselves projected over time. If they are, changes are expressed in terms of linear or exponential functions.

Each of these methods delivers a potential university entrance population, but none of them goes further to show the actual transfer into higher education. There is no doubt that this step is included in the model (in addition to "the structure of the secondary school system", "government policy on the provision of places in higher education" appears as a policy variable) but we have no information on the development from the above steps.

Example 7

In the sphere of macro-educational forecasting, A Demographic input-output model for educational forecasting (United Kingdom)(5) is one of the most original contributions for some time. Despite the fact that its primary purpose is not to be solely a tool for educational planning, it may prove to be very useful in this field.

The model is embodied in an input/output matrix, not of goods and services but of people; and whereas virtually all transition matrix models use study years as the transition poles, this model uses age years as the poles of a population accounting matrix and ignores study years entirely. This means it cannot be used for forecasting the school (educational) population by grade or year of study, but only by age. Different types of school and sex are cross-classifying variables so it is possible to discover new entrants and graduates as well as "stayers in the same type of school", all of them based on age.

These data give rise to a multitude of transition ratios which for forecasting purposes must themselves be forecast. Here, the model suffers from the (partial) imposition of the structure of the educational system on the data. Once the distinction between pupils in different types of schools is made (inevitable, since pupils of 15 in secondary modern schools exhibit different staying-on patterns from those in grammar schools), the projection of separate parameters for each type of school necessarily assumes that the structure of the system will remain substantially unchanged. This is so with virtually every forecasting model, but then most try and work from within the present structure of the system they are forecasting for; the present model starts outside the system, but for forecasting purposes is forced into it.

The manner of the projection of the coefficient is an innovation in the field of educational planning. Instead of using a linear trend (which often underestimates in the short-run and overestimates in the long-run) or an exponential trend (about right in the short term, overestimating in the medium term), the model uses sigmoid growth curves. This assumes that a small change in the value of the parameter is a function of the present value of the parameter and the difference between its maximum value and its present value. In mathematical terms,

$$\frac{dp}{dt} = \beta_p(\alpha - p)$$

Δ is a constant, p the transition coefficient, α its maximum value

$$\text{i.e. } p = \frac{\alpha}{1 + \left[(\frac{\alpha}{p} - 1\right] e^{-\beta\alpha^{t}}}$$

Not all transition proportions can follow this path, since the sum across any row must equal one; thus, there must be one residual proportion on each row. As yet, projections have not been done, so one cannot compare the effectiveness of this particular functional form with the more normal linear or exponential functions.

2. SIMULTANEOUS EQUATION MODEL

The *Parti* model (121), which had no empirical results at the time of this survey, uses linear multiple regression analysis to construct simultaneous supply and demand equations in which teacher numbers and three measures of teacher quality are made functions of school and neighbourhood characteristics as well as salary levels. The model offers a solution to the problem of how to use an educational production function to determine the best combination of inputs to an educational system. Parti starts with an ordinary linear production function. However, he hypothesizes - probably in part on the basis of the findings of the Coleman Report - that teacher numbers and average qualifications (measured by verbal ability, educational attainment and years of experience in teaching) will be the most important influences. He also hypothesizes that the other school inputs as well as characteristics of the student body and the neighbourhood in which the school is located will be important in attracting teachers to the school. He therefore adds four supply equations for the number and average qualifications of teachers to a simultaneous model. (There are also four demand equations in the model included in order to satisfy mathematical requirements for identification) which are to be used "as constraints in the [programming] problem of finding the estimated least cost combination of educational inputs which will produce a given desired average level of achievement for students in a school".

Presented below is a simplified version of both the structural and the reduced form of the model as well as the formulation of the problem for optimal resource calculation. (The complete model is presented pages 119-120). The main simplifications here are that a linear format has been assumed, that average teacher experience (EXP) and education (ED) have been omitted as exogenous variables because they operate in exactly the same way as average teacher verbal ability (V), and that the measures of school and neighbourhood characteristics have been aggregated into single variables, A and B. The number of teachers (T) has been substituted for class size (CS) in the production function in order to simplify calculations. The demand equations have also been combined with the supply equations because it is not clear from the meagre documentation available how the two will be separately measurable.

Simplified Structural Form

$$(1)\quad Q = q_o + q_t T + q_v V + q_a A + e_q$$

$$(2)\quad T = t_o + t_a A + t_w W_o + t_b B + e_t$$

$$(3)\quad V = v_o + v_a A + v_w W1 + v_b B + e_v$$

where Q = average score on a verbal test for students

T = numbers of teachers (in the original model this is the inverse of the class size times the number of students, but the formula has been simplified here in order to show the simultaneity more clearly).

V = average verbal ability of teachers.

A = a measure of school facilities (there are M in the original model but this has been simplified here).

W_o = the base salary of teachers

W_1 = the extra wage attributable to an extra unit of teacher verbal ability (presumably on the salary scale).

B = a measure of ethnic and socio-economic characteristics of the area served by the school. (In the original model the B enter only into the demand equations and are used to make the equations identifiable There are N in the original model).

e_q, e_t, e_v = stochastic error terms.

Q, T and V are the jointly dependent variables, of course, and the second stage reduced form of equation* looks like:

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* A biased estimator is one where the expected value of the estimated parameter, E ($\hat{q}$), does not equal the true value of the parameter, q. A consistent estimator is one where the plim (probability limit) of $\hat{q}$ does equal q. Thus, for large sample sizes the bias in the estimates will be small.

$$(1') \quad Q = q_o + q_t \hat{T} + q_v \hat{V} + q_a A + e_q$$
$$= q_o + q_t (\hat{t}_o + \hat{t}_a A + \hat{t}_w W_o + \hat{t}_b B) + q_v (\hat{v}_o + \hat{v}aA + \hat{v}_w W_1 + \hat{v}_b B) + qaA + e_q$$

where the ˆon the coefficients and variables indicate the estimated values from the first stage of the regression. Using ordinary least squares on (1') will give biased but consistent estimators of all the q parameters as for any simultaneous problem. Once these have been estimated, we can regroup the terms in (1') in order to show how Q will respond to an increase in any of the policy instruments. It will be noted that T and V are only indirectly policy instruments because they can be set only by manipulating the exogenous variables A, W_o, W_1, and B. The reduced form (1'') below tells us what the direct effect of a change in any of these will be on achievement.

$$(1'') \quad \hat{Q} = (\hat{q}_o + \hat{q}_t \hat{t}o + \hat{q}_v \hat{v}_o) + (\hat{q}_a + \hat{q}_t \hat{t}_a + \hat{q}_v \hat{v}_a) A$$
$$+ (\hat{q}_t \hat{t}_w) W_o + (\hat{q}_v \hat{v}_w) W_1 + (\hat{q}_t \hat{t}_b + \hat{q}_v \hat{v}_b) B$$

Let us now look at the way in which this simplified model could be used to calculate the minimum cost of producing a given achievement level. For this we will return to the structural form and we shall see that it is a quadratic problem in five variables, (T, V, A, W_o, W_1) and a dummy variable, 1. We can write it as:

$$\text{Min. } C = W_o T + W_1 V + pA$$

$$\begin{array}{llcl}
\text{subject to: } & \hat{q}_t T + \hat{q}vV + \hat{q}_a A & = & Q^* - \hat{q}o \\
& T \quad - \hat{t}_a A - \hat{t}_w W_o & = & t_b B^* + t_o \\
& V \quad - \hat{v}_a A \qquad - \hat{V}wW_1 & = & \hat{V}_b B^* + \hat{V}_o \\
& (T, V, A, W_o, W_1) \geqq 0 & &
\end{array}$$

where C = cost of a given combination of school inputs.
p = price of school characteristics A.
Q^* = a fixed level of average achievement desired by the school authorities.
B^* = the given characteristics of the neighbourhood which the school serves.

The interesting aspect of this model, in summary, is that it explicitly assumes interdependence among some of the school input variables and that it makes the school inputs dependent on price variables (wages) in such a way that the function to be maximized is non-linear in terms of the policy instruments and there is no longer any problem of constant marginal productivity and the simple comparison of marginal productivity to price ratios.

The results of this model were not available, however, and it remains to be seen whether the relationships hypothesized are strong enough and regular enough to give significant and reliable results. Even should the model give usable parameters, only application can show whether the correlation between teacher characteristics and school characteristics and wages is due to the ability of better schools to attract better teachers in the way specified by equations 2 and 3 and therefore whether manipulation of these policy instruments will actually have the desired effect on teacher numbers and quality.

Equations of the Parti Model

(1) $Q = f(V, EXP, ED, 1/CS, A_1, \dots, A_n)$
(2) supply: $T = g_o (w_o, A_1, \dots, A_n)$
(3) demand: $T = h_o (W_o, B_1, \dots, B_j)$
definitional equation: $1/CS = T(H)/s(R)$
(4) supply: $V = g_1 (W_1, A_1, \dots, A_n)$
(5) demand: $V = h_1 (W_1, B_1, \dots, B_j)$
(6) supply: $ED = g_2 (W_2, A_1, \dots, A_n)$
(7) demand: $ED = h_2 (W_2 \ B_1, \dots, B_j)$
(8) supply: $EXP = g_3 (W_3, A_1, \dots, A_n)$
(9) demand: $EXP = h_3 (W_3, B_1, \dots, B_j)$

Q = average score on verbal ability test.
V = average verbal ability of teachers in school.
ED = average number of years of education of teachers in school.

EXP = average number of years of experience of teachers.

CS = average class size in school.

A_i ($i = 1, \ldots, M$) measures of school facilities such as the average age of textbooks, presence of science laboratories, frequency of violence against teachers.

B_j ($j = 1, \ldots, I$) measures of ethnic and socio-economic characteristics of the area served by the school.

T = the number of teachers in a school.

H = the average number of hours spent by teachers in classrooms.

S = the number of students in the school.

R = the average number of hours spent by students in classrooms.

W_o = the base salary of teachers.

W_1 = W/V = the extra wage attributable to an extra unit of teacher verbal ability.

W_2 = W/ED = the increment in teachers' wages attributable to an extra unit of teacher education.

W_3 = W/EXP = the increment in teachers' wages attributable to an extra year of teacher experience.

(Note: the W variables are intended to be policy variables which can be used to attract more and better teachers to a given school. W_1, W_2, and W_3 are thus presumably increments on the salary scale which are accorded to teachers with higher qualifications as measured by verbal ability, education or experience, respectively).

Endogenous variables are Q, V, ED, EXP, T, W_o, W_1, W_2, W_3. Policy variables are the A_i and the W_k.

3. PARAMETER ESTIMATION AND TESTING OF MODELS

The respondents to the questionnaire answered questions pertaining to parameter estimation and the various techniques involved in such estimation and the sources and nature of data used. These questions, in turn, were supplemented with further queries on whether an attempt was made to measure changes of parameter estimations over time, whether the parameters were subjectively altered and the sensitivity analysis was carried out to test the effect on the solution of error in the estimation of the parameters.

The question that arises at the very outset is whether the parameters of the models are actually estimated in a statistical sense. In the case where the parameters are statistically estimated, information is given by the respondents on how these estimates were made. The relevant question is whether the estimates are based on the tabulation of data obtained from the statistical sources or if they are impressions of experts in government, industry, university, etc. or if they are results of econometric/statistical analysis. In the case where parameters are based on econometric/statistical analysis, the question is if these are derived from time-series data or cross-sectional data. The respondents also supplied information on the techniques employed in the estimation of parameters.

Four methods of parameter estimation were asked about in the questionnaire: tabulation of data; impressions of experts in government, industry, universities, etc.; econometric/statistical analysis and "other". Many models have parameter estimation by all these specified methods, but almost as common is tabulation by itself. Well documented examples of data tabulation are the Heidelberg model (30) and the Netherlands model (15); the short-term forecasting model of the Central Plan Bureau which, making forecasts for only one year ahead, uses only the most recently available data in parameter estimation. For the short forecasting period for which the model was built, the results have been found to be reasonably close to the actual figures, though a few adjustments of the model are recognised as necessary. On the other hand, Iceland (18), with an individualised data system permitting easy calculation of student flows, has not been so successful even with one-year forecasts.

Turning to the category of "experts' impressions", the biggest concentration of the use of this method occurs in the simulation models: twelve out of seventeen rely on the experts, though always in conjunction with at least one other method. The impressions have very often turned out to be judgements on the values of such parameters as student/teacher ratio, on the minimum number of hours per week a student should spend in small-group instruction in universities. In addition, we may include almost all the "other" category, which but for two exceptions /International Organisations Models (6), (82)7 consists of "legal" methods of parameter specification /Canada models 55, 56, 41 and United Kingdom (Scotland) model (66)7. They came from persons who suggested that a legal instruction or definition of the value of, say, a student/teacher ratio should not be classed together with a subjective judgement of the same thing. Most respondents, however, were content to include all such cases under "impressions".

Econometric/statistical analysis provides the widest scope for parameter estimation and has a short section to itself in the questionnaire. We shall disregard here problems of forecasting for each sex separately, or by different types of school, or by faculty. Admittedly, without such cross classifications global forecasting is likely to be less accurate, but there is no reason why the techniques employed should be substantially different from those used when plenty of data are available. A data problem which does confront the forecaster is what to do when he is confronted only by age group cohorts, not by study year cohorts. Assuming it is known to what point of time in the academic year the data refer, he may try to correct the age data to study-year figures. Depending on the rigidity of the educational system at school level the adjustment might not be too inaccurate, but at university level the lack of a fixed course length in so many countries, together with the problem of late entry, would only serve to confuse the issue still further.

The detail in which parameter estimation can be examined is dependent on the documentation available. At this stage it is not possible to present more than a summary of the information available from the questionnaires. For example, all the forecasting models using econometric/statistical analysis (ESA) in parameter estimation also attempted to measure changes in parameter values over time and so did many other models using only tabulated data and/or experts' impressions. Corresponding figures for the decision models are, six out of seven, sufficiently developed to have reached this point and all six of the simulation models are similarly advanced. However, measuring the changes was not always done using time series data. In one case, certainly /Italy (9)/, and in possibly several more of the forecasting models, the ESA was carried out using cross-sectional data; parameter changes must thus have been measured, either by repeated annual cross-sectional analysis or by one of the other two methods marked. There is a similar case in the decision models /France (72)/.

Simple regression is by far the most popular method of parameter estimation. A majority of the forecasting models, about 27, use ESA, of which eleven use simple regression alone; eight more do so together with multiple regression and a further three use both types of regression together with other multivariate techniques. There are three models which have indications in the "other" category: Germany (31), where the technique was unspecified and the Netherlands models (76), (77), where "graphical and table analysis" was used. Amongst decision models, three use multiple regression alone and elsewhere no technique or combination of techniques is used on more than one model.

In projecting the value of a parameter using purely mechanical methods there are always assumptions, either explicit or implicit, of some attribute of constancy concerning the parameter. The assumptions may be set down as follows:

i) attribute is constant in the past;
ii) attribute will be constant in the future;
iii) constant attribute in the future will be the same as the constant attribute in the past.

This attribute may refer to the value of the parameter itself, in which case no time-trend is observed and demographic forces constitute the only influence upon the future evolution of the population to be forecast. Alternatively, the attribute may be a constant annual increase in the absolute value of a parameter (implying a linear time trend) or a constant proportional annual increase in the value of a parameter (implying an exponential time-trend). These instances may be represented mathematically as follows:

i) $P_t = k$

P_t = transition proportion from time t-1 to time t. k is constant and is normally < 1. Here study years are being considered. This restriction does not necessarily apply when considering age-group cohorts.

ii) $P_t = a + bt$
iii) $\log_e Pt = a + bt$

If the equations (ii) and (iii) are to be estimated statistically, an error term εt is introduced on the right-hand side. In addition, data should be available for a "reasonable" number of years (say eight or more) or the estimates of the parameters will be imprecise. If such time series are not available, it is always possible to use the compound interest formula:

$$\text{iv)} \quad Y_t = Y_o (1 + R)^t$$

as a substitute for (iii) if it seems an exponential trend is being observed in fact, or the corresponding simple interest formula if the linear trend appears to be more likely. However, since neither of the interest formulas has the desirable properties of the least squares estimators of a and b in (ii) or (iii), they should be avoided if possible. In any case, which of the two formulas (ii) or (iii) should be applied can only be decided by examination of the data and of the respective R^2.

The transition ratio method is applied to population already in the education system. At certain points in the system, it is more difficult to predict accurately the state of the system in grade (x + 1) from the situation in grade (x). Such a point is, for example, the transfer between secondary and higher education. Instead of applying a transition ratio to the last year of school education, it is often possible to establish the ratio between the number of students of a certain age (the normal, or most common age for entry to university) and the total age-group population. With time-series data available, it is thus possible to establish a time-trend for an age specific enrolment ratio; assuming future age-group populations are known, it is then possible to forecast the number of x-year old students. In order to forecast the total number of students (by age) at university, it is necessary to establish age specific transition proportions. This method has been used by K. Mertens in forecasting the Belgian university population. However, instead of projecting changes in transition proportions over time, he used the following equations:

$$\text{v)} \quad P_{i,t} = a + b\, P_{i-1}^{t-1} + \varepsilon_t \quad \text{(i refers to age group)}$$

The 18 year old-age group was used as the basis for the enrolment ratio projections. When, as occurred on numerous occasions, the constant term was not significantly different from zero, b was re-estimated using:

$$\text{vi)} \quad \frac{\sum_t P_{i,t}/T}{\sum_t P_{i-1,t-1}/T} = \frac{\sum_t P_{i,t}}{\sum_t P_{i-1,\,t-1}}$$

This estimator, the ratio of the means, is unbiased, whereas the perhaps more obvious mean of the ratios:

vii) $$\sum_t \frac{P_{i,t}}{P_{i-1,t-1}} / T$$

is biased.

In a recent article on Mertens projections in particular and on the techniques of forecasting in general* Professor Meulepas suggests the use of an analysis of co-variance for examining time-series of a parameter when some structural change is known to have taken place which has affected the value of the parameter. An overall trend projection will be less accurate if such a change has given rise to two (or more) discernably different trends, particularly if the two trends can be shown to be statistically significantly different.

More generally, it is pointed out that there are some methodological objections to making forecasts of student proportion and then multiplying them by some future supposed population size. Strictly speaking, age-group population sizes or any group population sizes are random variables. Thus, any percentage with the group size as the denominator is a ratio of two random variables; and this brings all sorts of complications into the correct computation of means and variances. Even if the basic group sizes are regarded as deterministic, the percentage is then ratio P, with a variance.

$$S_p^2 = p\,\frac{(1-p)}{n} \quad \text{estimated by} \quad \hat{S}_p^2 = \frac{p(1-p)}{n-1}$$

The variance depends on n; deviations between estimates of the proportion and its true value also depend on n, and n itself varies with time. In this case, the residuals are correlated with the explanatory variable and the least squares estimator should not be used. Ignoring this, it is still the case that not all the observations have the same variance, and generalised least squares should be used as a weighting device. To avoid all these difficulties, Meulepas himself suggests an ordinary multiple regression relating the number of students by age to age-group population and time. In this case, if the time regression coefficient happens to be insignificant, the age-group coefficient is the same proportion, now assumed constant, to which ojections have already been made.

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* "Critical Survey of the Forecasting Methods in a Belgian University". Population Forecasts; Centre for Economic Studies, Catholic University of Louvain.

Explanatory Models

We will now turn to the descriptive/analytic models. Exactly half this group have stochastic equations in the model, two-thirds of which claim to use regression as a solution procedure. Concerning parameter estimation, slightly under half use data tabulation and over two-thirds use ESA but, it may be supposed, the experts' impressions are little sought after in view of the nature of the approach. Cross sectional data are far more commonly used than time series data. Fifteen out of seventeen models using ESA for parameter estimation do so using multiple regression; only six use simple regression, whereas nine use "other multivariate techniques", a very rare category elsewhere. This latter point must again be because of the type of analysis being done. An example of this model can probably give the best idea of the type of problem tackled.

The United States model considered is an example of the educational process viewed as a production function (34). There are eleven endogenous variables. The first equation relates the probability of a student with certain characteristics leaving the educational system, in a certain output category, to two types of variables: the characteristics and resources the students bring to the educational process - past high-school scores, parental income, study hours per week and so on; and the resources which the educational institution brings to bear on the student - quality of staff and other facilities, for example. Going back one level, there are three equations for determining three different aspects of the mental resources the student brings to higher education. The equations relate such variables as parents' education and income and number and type of staff at high school. A fifth equation relates the finance available to the student while in college and parental income. Finally, there are six equations tracing the direct effect of parental education and occupation on the college performance of the student. All the equations are linear in natural logarithms.

The real meat of the model is in the estimation of the first-mentioned probability, and of the three aspects of mental resources from the next three equations. These can be estimated in four different ways.

i) By assigning a value of 1 to the dependent variable when the student fails in the given output group A and 0 otherwise. But when the probability of the event A is P, the variance of the error of the estimate depends on P; the condition of homoscedasticity is violated, and we do not have minimum variance, unbiased parameter estimates.

ii) By grouping the data to obtain a prior estimate of the probability of A, given the exogenous variables. This implies that the results of a group of individuals can be averaged out over the group, but the dependent variable is the log of the average odds of success for the group, which does not equal the average of the log of the odds of success for each individual. There are other objections to this method.

iii) A method for estimating the parameters can be derived from discriminant analysis.

iv) There is finally the possibility of using the principle of maximum likelihood to estimate the parameters.

The last two methods do not have the methodological objections applicable to the first two - but they are more complex, and therefore more costly, in terms of man hours and computer time.

Sensitivity Analysis

Sensitivity analysis is widely regarded as an important step for testing the model. Though there is little information on the subject in the documents collected by the survey, it is however possible to distinguish different types. In one group by themselves are those mathematical programming models where the coefficients in the preference (objective) function are varied to examine the effect on the solution. France (72) is an example of this: there are ten different objective functions giving different weights to various components of consumption. A different type of sensitivity analysis is that where policy parameters are varied. (Some policy parameters may also be the coefficients of a preference function, but we refer here to parameters appearing in the structure of the model - and thus to models in general, not specifically programming models.) The results then show the effect of various policy decisions. An example here is the Norway model (65), where the effect on costs of increasing upper secondary school class sizes (in some country districts they are about seventeen to twenty-five) is examined.

The most common kind of sensitivity analysis is when as many parameters as possible are varied. The mere fact that this occurs is not so interesting as the bases upon which the alterations are made. In a forecasting model /USA model (11)7 the different parameter values were specified using different methods of parameter estimation. Denmark model (1) is a simulation model examining the relationship between the total number of new entrants to teacher training institutions and average class size, when different class choices are offered and a maximum class size is imposed. The parameters were varied according to the values found at individual institutions from which the data were originally drawn. One of the most comprehensive examples of "general sensitivity" is Germany (31), a higher education projection model for Baden-Württemberg. With four types of higher education (universities, teacher training institutions, higher engineering schools and higher "culture" schools) and up to twelve subject-groups which could be studied at each institution, with immigration data for non-Baden-Württemberg Germans and for foreigners, the parameters varied were: the drop-out rates between qualifying for higher education (Abitur) and actually commencing study; the percentage distribution of students over institutions (teacher training entry can be controlled, the others are in general unrestricted); the percentage distribution over subjects; transition proportions, success rates; and immigration proportions for Germans and foreigners.

The final kind of sensitivity analysis to be considered is that searching for, or examining the effect of, crucially sensitive parameters. Two cases may be distinguished. First, the model-builder varies at what is assumed to be a crucially sensitive parameter - for example, the transition coefficient between schools /Germany model (8)7. More painstaking is the process of examining each parameter to discover which are crucially sensitive. This procedure has a possibility of "rejection" in that a parameter found to be crucially sensitive in the model may not be so regarded by the policy makers, and the model work may be rejected because of this. From Germany (31) we have the situation that the main results of the model have been accepted, but some of the results of the sensitivity analysis have not. Reasons for this and further examples of the same situation, are not forthcoming.

Testing and Evaluating

Testing and evaluating the results of the model should have a more prominent place than it holds at present. The possibility of comparing the results of the model with actual data depends to a large extent on the type of model. By far the greatest opportunity for such a comparison lies with the forecasting models. It is thus surprising that so many of the respondents failed to indicate that any comparison had been made, or failed to indicate the results of such a comparison. Norway model (1) claimed statistical reasons for its disappointing forecasts; but Iceland, with its individualised data system, offered no reason for its poor results. In the Belgium model (87) where a single university is studied, a priori inter-institutional comparison of transition coefficients was tried before running the model. Belgium model (86) "changed" its parameter values when regressions were not statistically significant. But there is no indication that there was a fundamental re-thinking on the structure of the model. This raises the whole question of the validity of any particular model to the system it purports to represent; this point is acknowledged in the Netherlands' short-term forecasting model (75) but does not seem to have widespread acceptance. There is often comparison between the results of different forecasts [Belgium model (13)]. Most amusing is Germany model (1), a cost projection model, whereby one year's projections were compared with the budget and found to be very close; unfortunately, neither set of figures turned out to be close to the actual expenditures.

For decision and simulation models there seems to be no general method of testing the results, as is possible with forecasting models. This is due to the wide variety of problems tackled; a few examples can perhaps best illustrate the point. A linear programming model, optimising the location of new industrial high schools by minimising the travel time of students, had its "optimal" sites compared on a map with present student population clusters; the sites seemed to be "reasonable" in terms of the problem posed [Belgium model (52)]. The Danish simulation model results were compared with individual institutions from which data had originally been culled and were again felt to be reasonable. In the United Kingdom, a model was used for the allocation of government grants and loans to local education authorities in Scotland; a Chi-squared statistic was calculated, comparing actual expenditure by each authority with the grants to each authority. Just what the hypothesis was, or what the result of the calculation was, has not been discovered /United Kingdom model (66)7.

Finally, we may point out that it would be very helpful, not only to the educational planners but to the researchers themselves, if confidence intervals could be calculated for forecasts where they are appropriate, that is to say, where stochastic techniques have been employed in projecting enrolment ratios, transition coefficients and the like. It is always useful to have some idea of the inherent error of a particular method.

Use of Computers

The respondents were asked to report on the use of any computers in either estimating the parameters of the model or in deriving numerical solutions. They were also asked to furnish information on any special algorithms that were developed to meet the special needs of the model in question. /Annex 2, Part A entitled "Basic Characteristics", provides information as to the type and model of the computer used in the 73 cases for which this information was available7.

Chapter VII

CASE STUDIES OF MODELS

This chapter covers three case studies which represent some of the commanding heights of the uneven terrain of mathematical model-building in education. The first study gives the outline of a large model constructed in Norway to predict enrolments in the post-secondary education sector. To illustrate the working of the model, we have drawn a detailed diagram showing the relationship among the variables and the coefficients that indicates the intensity of those relationships. The numerical examples of the sensitivity of the solution and variations in these coefficients are taken from the author to illustrate the nature and problems of using such a model. The second study was written by the model-builders themselves. It shows, in summary, the most recent version of a model which was covered by the survey in its early **form**. In its current state the model now covers all sectors of education for the Federal Republic of Germany as a whole. Its major contribution is the introduction of feedbacks, which are usually neglected in models describing education as a flow system. Futhermore, the work goes a long way towards treating explicitly the problem of variability of transition coefficients, which are usually assumed constant. The third study covers a number of "behavioural" models concerned with the factors determining the achievement of students and the productivity of educational institutions.

1. ENROLMENT PREDICTION MODEL OF NORWAY

Introduction

The model for predicting educational enrolment and output in the post-secondary educational system of Norway (12) is the work of the Research Department of the Norwegian Research Council for

Science and the Humanities (NRCSH). It has been developed along the lines suggested by a more general work of Tore Thonstad (Tore Thonstad, "A Mathematical Model of the Norwegian Educational System", in OECD Mathematical Models in Educational Planning, Paris, 1967 and Education and Manpower: Theoretical Models and Empirical Applications, London: Oliver and Boyd, 1969). It covers only the post-secondary sector of education. This sector of education is not linked with the economic or manpower system.

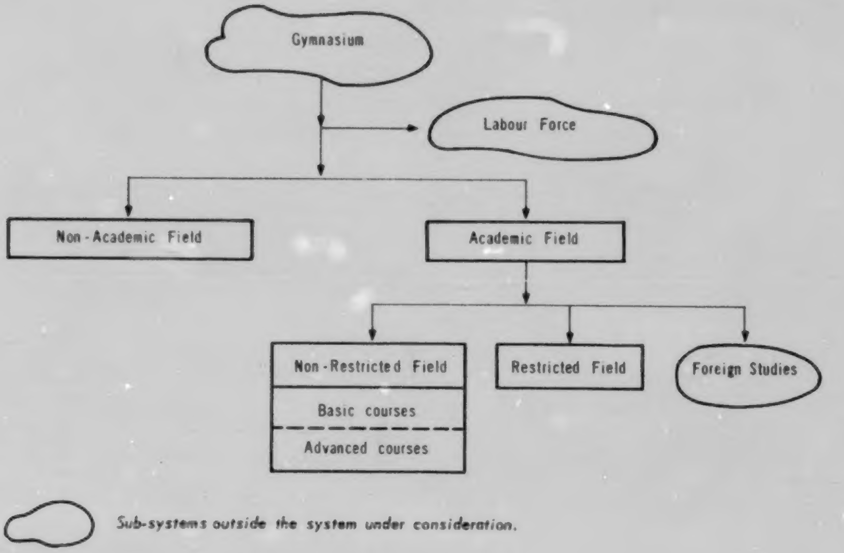
The Research Department has had the task of making projections of enrolment and output in post-secondary institutions. These projections, however, seem to have lacked overall consistency. The purpose for the development of the present model, therefore, was to increase the accuracy of the forecasts by making them internally consistent with regard to the future evolution of post-secondary education as a whole. The model aimed at forecasts of enrolment and output, under alternative hypotheses regarding the future participation rates, transitions and drop-out coefficients.

In general, the education system of Norway at the post-secondary level is made up of educational processes which may be grouped in four fields of study, namely:

a) the restricted academic field (or closed university);
b) the non-restricted academic field (or open university);
c) the foreign academic field (the foreign academic field does not belong to the educational system of Norway, but it is considered because it receives many of the gymnasium graduates who cannot be admitted to the closed university); and
d) the non-academic field (the educational processes in the non academic field are of a non-university level but for admission the matriculation examination is required).

The above grouping is essential for the understanding of the structure of the model as there are specific rules that govern admissions to the various fields.

We will describe the admission possibilities with the help of the Diagram VII.1:


Gymnasium
Labour Force
Non-Academic Field
Academic Field
Non-Restricted Field
Basic courses
Advanced courses
Restricted Field
Foreign Studies
Sub-systems outside the system under consideration.

After the gymnasium graduates take their matriculation exams (examen artium) they either join the labour force or they pursue further studies. They can choose to join either the "non-academic" field or the academic one. In the academic field they have the following choices:

a) to apply to an educational process in the restricted field;
b) to apply to an educational process in the non-restricted field; or
c) to study abroad.

The admission to the restricted field depends on the places available (capacity) in each educational process in each academic period. This means that there is a high probability that not all of those who apply to the restricted field will be admitted. In the case that the number of applicants is greater than the capacity of the various processes, those who will not be admitted have to choose one of the following: to enter an educational process in the non-restricted field (secondary admission); to travel abroad to pursue studies in the educational process of their first choice, or to repeat the matriculation examinations in order to improve their grades so that the next year they will be admitted in the educational process of their first choice at home.

Among the possible flows there are transitions from one field to another. This is true mainly from educational processes in the restricted field to educational processes in the non-restricted field (usually because of the difficulty of studies in the restricted field). Since the restricted field is characterised for the fixed places in the various educational processes and the demand for those places seems to be greater than their total number, admission to the restricted field has been exogenously determined. This is true also for the non-academic field as well as the foreign studies, whereas admission to the non-restricted field is calculated from the model.

Two types of admission to the non-restricted field are distinguished: the primary admission and the secondary admission. The primary admission includes all gymnasium graduates who make an educational process in the non-restricted field their first choice. (An interval of up to three years between the taking of the matriculation examination and the beginning of study is considered in the model. This was important in order to take care of drafting or required field work before entering a university.) The secondary admission includes those gymnasium graduates who have not been admitted to the restricted field and were distributed to the various educational processes of the non-restricted field.

The Mathematical Structure of the Model. The model is a system of recursive equations. Its general mathematical form is as follows:

1. $A_r(t+T) = a_r(t+T)\, A(t+T)$

2. $Y_r(t+T) = k_{0,r}(t+T)\, A_r(t+T)$
   $Z_r(t+T) = k_{1,r}(t+T)\, A_r(t+T)$
   $W_r(t+T) = k_{2,r}(t+T)\, A_r(t+T)$
   $U_r(t+T) = k_{3,r}(t+T)\, A_r(t+T)$

3. $Y_r(t+T) = l_{0,r}(t+T)\, X_r(t+T)$
   $Z_r(t+T) = l_{1,r}(t+T+1)\, X_r(t+T+1)$
   $W_r(t+T) = l_{2,r}(t+T+2)\, X_r(t+T+2)$
   $U_r(t+T) = l_{3,r}(t+T+3)\, X_r(t+T+3)$

4. $B(t+T) = \sum_r \left[Y_r(t+T) + Z_r(t+T) + W_r(t+T) + U_r(t+T) \right]$

5. $S(t+T) = s(t+T)\, A(t+T)$

6. $R(t+T) = S(t+T) - B(t+T)$

$$7.\quad C_r(t+T) = Y_r(t+T) + Z_r(t+T-1) + W_r(t+T-2) + U_r(t+T-3) + V_r(t+T)R(t+T)$$

$$8.\quad M_r(t+T) = \sum_{i=i}^{10} f,r,i\ (t+T-1)\ N_{r,i}\ (t+T-1)$$

$$9.\quad E_r(t+T) = \sum_{i=1}^{10} [h_{r,i}(t+T-1) + v_{r,i}(t+T-1)]\ N_{r,i}(t+T-1)$$

$$10.\quad X_r(t+T) = C_r(t+T) + \sum_{s=1}^{19} m_{r,s}(t+T)\ M_s(t+T) + \sum_{s=1}^{9} e_{r,s}(t+T)\ E_s(t+T)$$

$$11.\quad N_{r,i}(t+T) = X_r(t+T) \text{ for } i=1$$

$$12.\quad N_{r,i}(t+T) = c_{r,i-1}(t+T-1)\ N_{r,i-1}(t+T-1) \text{ for } i = 2....10$$

$$13.\quad N_r(t+T) = \sum_{i=1}^{10} N_{r,i}(t+T)$$

$$14.\quad N(t+T) = \sum_{r} N_r(t+T)$$

The explanation of the symbols used is as follows:

Endogenous Variables

$X_r(t+T)$	Admissions to a certain educational process in year t+T (non-restricted field).
$M_r(t+T)$	The number of drop-outs from a certain educational process during the academic year t+T-1/t+T.
$N_{r,i}(t+T)$	The number of students in activity No. r,i in year t+T.
$N_r(t+T)$	The total number of students enrolled in a certain educational process in year t+T.
$N(t+T)$	The total number of students enrolled in all educational processes in year t+T.
$E_r(t+T)$	The number of graduates from a certain educational process during the academic year t+T-1/t+T.

Exogenous Variables (Data)

$A(t+T)$	The number of gymnasium graduates (gymnasium cohort) in year t+T.
$X_r(t+T)$	Admissions to a certain educational process in the restricted field, foreign studies and non-academic education.

$N_{r,i}(t)$	The number of students in each activity in the base year (t).

Intermediate Variables

$A_r(t+T)$	The number of gymnasium graduates in year t+T seeking admission to a certain educational process.
$Y_r(t+T)$	The number of gymnasium graduates from the t+T-cohort entering a certain educational process the same year of graduation.
$Z_r(t+T)$	The number of gymnasium graduates from the t+T-cohort entering a certain educational process the year after graduation.
$W_r(t+T)$	The number of gymnasium graduates from the t+T-cohort entering a certain educational process two years after graduation.
$U_r(t+T)$	The number of gymnasium graduates from the t+T-cohort entering a certain educational process three years after graduation.
$B(t+T)$	The total number of gymnasium graduates from the t+T-cohort entering the field of study of their first choice.
$S(t+T)$	The total number of gymnasium graduates in year t+T seeking admission to post-secondary institutions.
$R(t+T)$	The total number of admission seekers who have not succeeded to enter the field of study of their first choice [is the difference between S(t+T) and B(t+T)].
$C_r(t+T)$	New admissions to a certain educational process in year t+T.

Lagged Intermediate Variables

$N_{r,i}(t+T-1)$	The number of students enrolled in activity i of a process r at the beginning of the year.
$N_{r,i-1}(t+T-1)$	The number of students enrolled in the preceding activity (i-1) of the previous year.
$Z_r(t+T-1)$	The number of gymnasium graduates who are admitted in year t+T to a certain educational process but have graduated from the gymnasium one year ago.
$W_r(t+T-2)$	The number of gymnasium graduates who are admitted to a certain educational process in year t+T but have graduated from the gymnasium two years ago.

$U_r(t+T-3)$	The number of gymnasium graduates who are admitted to a certain educational process in year t+T but have graduated from the gymnasium three years ago.

Coefficients Exogenously Determined

$s(t+T)$	Total study propensity for the gymnasium graduates in year t+T.
$a_r(t+T)$	Particular study propensity for a certain educational process for the gymnasium graduates in year t+T.
$k_{j,r}(t+T)$ and $l_{j,r}(t+T)$	The fraction of the t+T gymnasium cohort entering a certain educational process j years after graduation.
$\nu_r(t+T)$	Distribution coefficient for secondary admission to basic courses in the non-restricted field in year t+T.
$f_{r,i}(t+T)$	Drop-out coefficient.
$h_{r,i}(t+T)$ and $v_{r,i}(t+T)$	Graduation coefficient: h for autumn term; v for spring term.
$m_{r,s}(t+T)$	The fraction of the number of drop-outs from an educational process r during the academic year t+T-1/t+T entering another educational process s in year t+T ($r \neq s$).
$e_{r,s}(t+T)$	The fraction of the number of graduates from a basic course of study during the academic year t+T-1/t+T entering an advanced course of study in year t+T.
$c_{r,i}(t+T)$	The fraction of the number of students enrolled in activity i in a certain educational process r at the beginning of the year t+T who next year will be enrolled in the activity r, i + 1.

Other Symbols

$r = s$	Educational process.
i	Activity of an educational process.
t	Base year.
T	Years in the planning period.
j	Years between taking the matriculation examination and beginning of post-secondary study.

Description of the Model

Each year for a gymnasium cohort, A(t+T), there are certain propensities for certain educational processes, $a_r(t+T)$, which determine the admission seekers for each process, i.e. the number of gymnasium graduates, $A_r(t+T)$, who would like to pursue post-secondary studies in a certain educational process, r. Some of these graduates begin their studies in the same year (year of graduation from gymnasium), some begin the following year, some two years later and some three years later. These are estimated as a fraction of the total admission seekers for each educational process $A_r(t+T)$ and are determined by interval coefficients kjr (where j = 0,1,2,3), respectively. Applying these coefficients to the admission seekers $A_r(t+T)$, we get the number of the gymnasium graduates of a certain gymnasium cohort who will begin post-secondary studies the same year $Y_r(t+T)$, the year after, $Z_r(t+T)$, two years after, $W_r(t+T)$, and three years later, $U_r(t+T)$, respectively. If we sum all four over the process r, we get B(t+T) which shows the total number of gymnasium graduates of a certain gymnasium cohort who will sooner or later enter the post-secondary fields of study. In addition, B(t+T) shows those who will be admitted to the educational process of their first choice. If, on the other hand, we assume that S(t+T) is the total number of gymnasium graduates of a certain gymnasium cohort who wanted to pursue post-secondary studies [S(t+T) = s(t+T) A(t+T) where s(t+T) is the total study propensity], B(t+T) may be equal to S(t+T) or different. If their difference, R(t+T), is positive, we then have a number of gymnasium graduates not being admitted to the field of study of their first choice, and they must either refrain from further post-secondary education, or places must be made available for them in the restricted fields, or they must be distributed among the educational process of the non-restricted field (provisions are made for those who will be sent abroad to study). This distribution is made with the aid of distribution coefficients, $\nu_r(t+T)$, that are applied to R(t+T).

The new admissions $C_r(t+T)$, therefore, for the basic courses in the non-restricted field in any year (t+T), are the sum of the primary admission at that year, $[Y_r(t+T) + Z_r(t+T-1) + W_r(t+T-2) + U_r(t+T-3)]$, plus the secondary, i.e. those that have been distributed to the non-restricted field, $\nu_r(t+T).R(t+T)$.

The total admissions, on the other hand, are the sum of the new admissions, $C_r(t+T)$, plus those that have been dropped out from other processes (s) and enter another process $r (r \neq s)$.

These are calculated as a fraction $m_{r,s}(t+T)$ of the total drop-outs of the various processes, $M_r(t+T)$.

In order to make the equation more general, and be able to take care of those who have graduated from the basic courses and follow advanced courses, we add the term $e_{r,s}\ E_s(t+T)$, where $e_{r,s}$ is the fraction of the number of graduates from a basic course of study in year t+T, whereas $E_s(t+T)$ is the number of graduates of the basic courses of a certain educational process.

$E_s(t+T)$ and $M_r(t+T)$, on the other hand, are estimated as definite fractions of the number of students enrolled in activity i of a process r at the beginning of the year $[N_{r,i}(t+T-1)]$ with the use of the graduation coefficients $h_{r,i}(t+T-1)$ and $v_{r,i}(t+T)$ and the drop-out coefficient $f_{r,i}(t+T-1)$, respectively.

The total enrolment in each activity, $N_{r,i}(t+T)$ is made a definite fraction, $c_{r,i-1}(t+T-1)$ of the number of students in the preceding activity of the previous year, with the exception of the first activity in each process (i=1) where the total enrolment is equal to total admissions.

Solution and Use of the Model(1). For the empirical application of the model, a total of 58 educational processes have been considered: 9 basic and 10 advanced courses in the non-restricted field, 18 in the restricted field, 5 for studies abroad and 16 in the non-academic field. Each process has 10 activities (i = 10). The number of equations is 4,876. Out of those, 4,840 are "definitional" and 36 "legal-institutional". Of the definitional, 1,360 have to do with enrolments and 3,480 with outputs. There are 2,846 instantaneous, 1,856 are lagged first order and 174 are are lagged second or higher order. The model determines the values of all variables at intermediate periods, the length of which is equivalent to an academic term (two per year).

The estimates of the parameters of the equations were made on the basis of:

1. Tabulation of data. [The sources of data used are: (a) regularly collected enrolment and graduate statistics from CSO; (b) special surveys for cohort data on gymnasium graduates on individual data forms. Also, records (computerised) for all graduates from post-secondary schools (used for initial stocks).]

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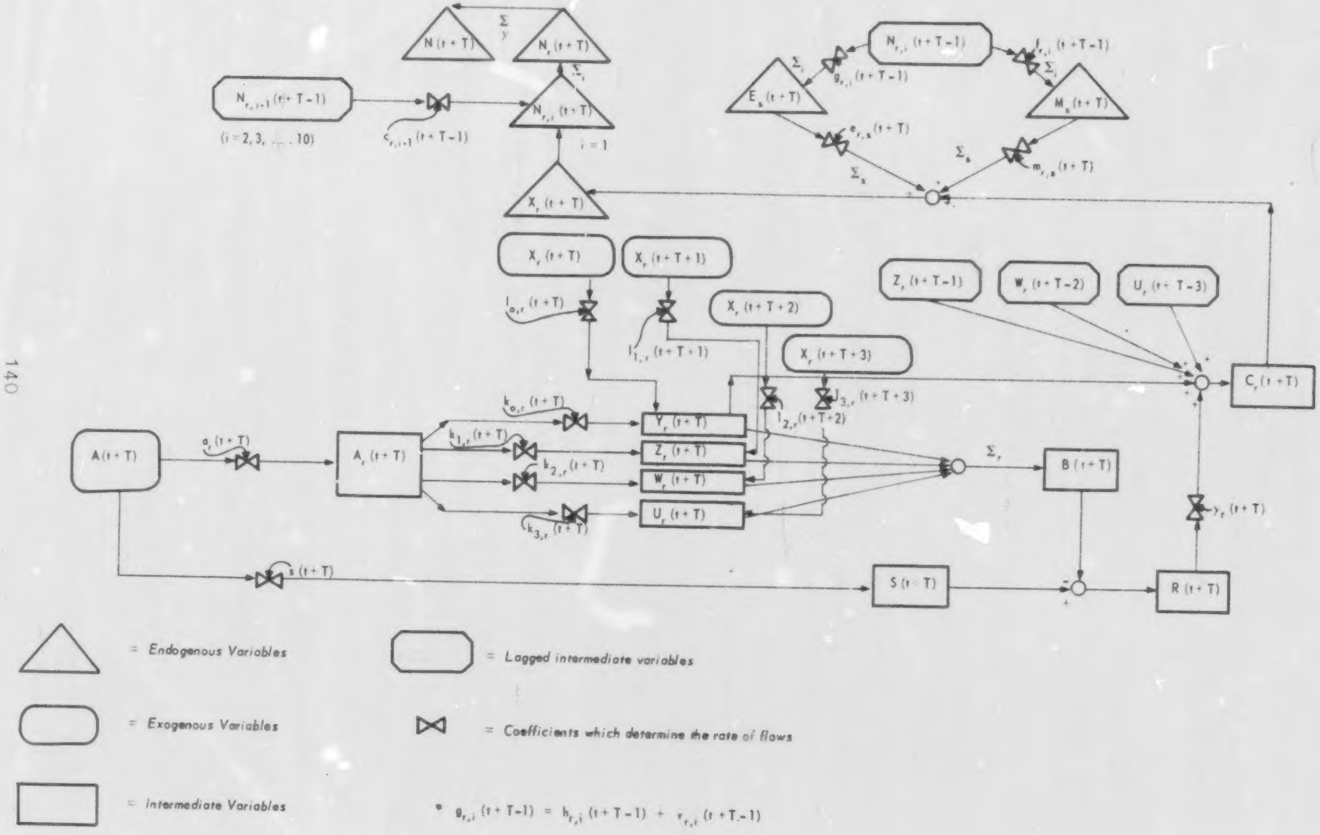
1) For the various educational processes that have been included, see Eva Birkeland, En Modell for Beregning av Fremtidig Studenttilgang, Studentmasse og Kandidatproduksjon i det Postgymnasiale Utdanningssystem i Norge, NVAF, Oslo 1967, pp. 123-124.

Figure VII.2. FLOW-DIAGRAM OF THE MATHEMATICAL MODEL OF THE NORWEGIAN POST-SECONDARY EDUCATIONAL SYSTEM


N(t+T)
Σ y
N_r(t+T)
Σ_i
N_{r,i-1}(t+T-1)
(i=2,3,...,10)
c_{r,i-1}(t+T-1)
N_{r,i}(t+T)
i=1
X_r(t+T)
N_{r,i}(t+T-1)
Σ_i
g_{r,i}(t+T-1)
E_s(t+T)
f_{r,i}(t+T-1)
Σ_i
M_s(t+T)
e_{r,s}(t+T)
Σ_s
Σ_s
m_{r,s}(t+T)
X_r(t+T)
X_r(t+T+1)
X_r(t+T+2)
X_r(t+T+3)
l_{o,r}(t+T)
l_{1,r}(t+T+1)
l_{2,r}(t+T+2)
l_{3,r}(t+T+3)
Z_r(t+T-1)
W_r(t+T-2)
U_r(t+T-3)
C_r(t+T)
A(t+T)
a_r(t+T)
A_r(t+T)
k_{o,r}(t+T)
k_{1,r}(t+T)
k_{2,r}(t+T)
k_{3,r}(t+T)
Y_r(t+T)
Z_r(t+T)
W_r(t+T)
U_r(t+T)
Σ_r
B(t+T)
y_r(t+T)
s(t+T)
S(t+T)
R(t+T)
= Endogenous Variables
= Exogenous Variables
= Intermediate Variables
= Lagged intermediate variables
= Coefficients which determine the rate of flows

$* \; g_{r,i}(t+T-1) = h_{r,i}(t+T-1) + v_{r,i}(t+T-1)$

2. Econometric/statistical analysis using time-series as well as cross-sectional data.

The econometric techniques employed for the estimation of the parameters were mostly simple and multiple regression; in some cases, however, other multivariate techniques were also used. (We do not have enough information on the techniques used for the estimation of the parameters and how these techniques have been used.) The estimates of the parameters, however, have been altered subjectively by the model-builders on the basis of intuition. This seems to have been necessitated by the fact that the validity test of the results (comparison of forecasts with actual data) which they have attempted were disappointing.

The Numerical Examples. Five numerical examples were calculated under different assumptions concerning the propensities to study, by altering the coefficients, $s(t+T)$ and $a_r(t+T)$. This procedure was used at the same time as sensitivity analysis to study the effect of changes on these parameters on the solutions(1).

In four numerical examples, the number of gymnasium graduates for 1966-85 (the base year was 1965-66) was taken directly from the predictions prepared by the NRCSH using alternative II for the first two, and alternative I for the other two examples(2) plus a supplement of 10 per cent for the graduates from the commercial gymnasium. In the fifth numerical example they have used for the period 1966-73 the same data as in the first example, and for the period 1974-85 they assumed the gymnasium graduates to be 25 per cent of the 19½ age-group, plus the 10 per cent supplement for the graduates from the commercial gymnasium.

The total study propensity $s(t+T)$ in four examples was assumed to be .50 in each year. In the fifth example, it was assumed to increase from .50 in 1966 to .60 in 1975, and to remain constant thereafter. The particular study propensities $a_r(t+T)$ for the basic courses in the non-restricted field were estimated on the basis of 1965 data and were assumed to remain constant over

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1) Two alternative methods have been used for calculating admissions to the basic courses in non-restricted fields of study. In alternative I, the calculations were made from the assumed particular study propensities. In alternative II, secondary admissions have been considered because of bottlenecks in the system.

2) For the predictions and the assumptions under which alternatives I and II have been calculated, see: Eva Birkeland, A Model for Predicting Educational Enrolment and Output in the Post-Secondary Educational System of Norway, NRCSH, Oslo, 1967, page 27.

the prediction period in four examples. (It was found that the model-builders have attempted to measure changes of both the particular as well as the total study propensities using statistics for the years 1964-67. But because of the quality of the data, the results were not satisfactory.) In the fifth example, the particular study propensities for the social sciences were assumed to increase and the propensities for humanities to decrease from 1966 to 1975 and to remain constant thereafter.

The assumed propensities in the four examples, and the way they have been changed in the fifth example, are shown below:

Assumed propensities / Field	In four examples throughout the period	In the fifth example for 1975 and thereafter
	%	%
Humanities	16.40	10.10
Law	4.00	4.00
Theology	.90	.90
Natural Sciences	9.00	9.00
Economics	2.00	3.00
Psychology	2.00	3.00
Pedagogy	.80	2.00
Sociology	.30	2.00
Political Science	.60	2.00

Under these assumptions, they have generated a number of alternative forecasts for enrolment and graduates (output) throughout the forecasting period.

The forecasts produced by the model have been accepted by the officials of the Ministry of Church and Education and are being used by the University Study Unit of the same Ministry for estimating future expenditures for universities and colleges.

In the model under review, the number of students in each activity in any year is made a fraction of the students in the preceding activity during the previous year. For the first activity, however, they are made equal to the total admissions into the particular educational process. From that, at least two implications follow: first, there are no repeaters in the first activity of each educational process; and, second, there are no new entrants into any other process except the first one. But from what we know this does not seem to be realistic and the assumption made about the number of students in each activity is an over-simplification of reality.

It is true that in most of the educational processes, especially in the non-restricted field, there are no final examinations for each given course at the end of each term. This means that the students can proceed to take the courses offered in the next term and, therefore, it will not be possible to speak about repeaters. But in specific time intervals, the students have to take and pass examinations on the subject-matter taught during the previous terms. In economics, for example, in the non-restricted field, a student has to pass four examinations during his studies at the undergraduate level. The first is taken immediately after the first term and it is on general course work (philosophy, logic and psychology). The second is taken during the second term in mathematics. The third is taken at the end of the fifth term and it is in economics. The fourth examination is taken at the end of the sixth term and it is on statistics. Although the passing of any of these examinations is not a prerequisite for a student in order for him to take further courses, in reality, however, the students who fail in any of these examinations delay their study programme in order to prepare themselves more adequately and repeat the examination. Through this alone one can explain why it takes much longer than it should for many students to finish their studies. We are not considering here any other factor which may cause a delay in a student's study programme (e.g. interruption of studies for work) but only the inadequate preparation of the students to pass their examinations.

The above suggests that in reality we do have repeaters in several activities, including the first, and more so in those educational processes in which more rigid study programmes are followed, such as the natural sciences in the non-restricted field, and almost all educational processes in the restricted field. On the other hand, the less rigid the study programme is, the more irregular the study pattern becomes and, therefore, the less constant are those coefficients which measure the number of students who go from one activity to the next.

The second implication of the assumption made about the number of students in each activity, i.e. that there are no new entrants in any other activity but the first one, could also be shown to be unrealistic. In the model, new admissions, i.e. new entrants, to an educational process in the non-restricted field $X_r(t+T)$, occur only in the first activity of the basic courses (undergraduate level) or the first activity of the advanced courses (graduate level) of this process. We expect, however, to have new entrants in each activity. These new entrants may come from:

a) other educational processes of the same educational system;

b) the same or other educational processes from abroad; and

c) the labour force.

From the labour force we expect those who have interrupted their studies at a certain level in order to work, and after a while re-entered the educational system, at the same level they were at before they left, to continue their studies. A special case will be those who have served in the army. In the model we find only transitions from other educational processes, $m_{r,s}(t+T) \cdot M_s(t+T)$, as a component of the new admissions, $X_r(t+T)$ which, as we said, occur only in the first activity. This means that transitions from one educational process to another occur also in the first activity which, of course, is not the case. Because of limited information the transition coefficients $m_{r,s}(t+T)$ have assumed to be zero in the five numerical examples which are discussed below.

Apart from the transitions, there is no consideration of the other types of new entrants. The numbers for these types of new entrants may be very small, but still they must appear as components of the definitional equation for new entrants. In general, it is helpful for planning purposes to disaggregate the total number of students in each activity into the following three components: repeaters, new entrants and those who are promoted from one activity to the next.

Another item which is not treated in the model is mortality and/or inactivation of students during their studies. This means that the model cannot show the alterations in the number of students flowing through the educational system due to mortality and for other reasons that make the students inactive. For planning purposes, however, establishing the number of students who die and/or became inactive, is of great importance since this will suggest necessary corrective actions.

The most serious weakness of the model is perhaps the lack of any behavioural explanations of what is actually happening within the educational system. Out of the 4,876 equations of the model, not a single equation can be regarded as behavioural. The absence of behavioural elements in the model makes the model-building effort an accounting exercise. The model, instead of explaining the behaviour of the variables of the educational system, is based entirely on past flow relationships. The values of the coefficients are estimated from outside the model by tracing a gymnasium cohort through the post-secondary sector of the educational system and tabulating the numbers. There is no indication of the causes of changes in the value of the coefficients. For instance, we know that a student who enters a certain educational process, or drops out from the system, has some specific reasons for doing so. These are not the same for all the students in the same year, or from one year to the next. A model, therefore, in order to describe adequately the educational system at any time, must incorporate behavioural elements. Otherwise, the model-builder himself will have to keep changing the values of the coefficients according to his intuitive judgement, so that he can take into account changes in behavioural patterns.

Of course, the above criticism does not apply to the Norwegian model alone, but to many others that use simple bookkeeping methods for estimating the values of the parameters of a model, thereby attempting to describe a complex and dynamic system such as the educational system.

Evaluation and Sensitivity Analysis of Some of the Coefficients. The estimation of the interval coefficients $[k_{j,r}(t+T)$ and $l_{j,r}(t+T)]$ as well as the continuation $[c_{r,i}(t+T)]$, graduation $[h_{r,i}(t+T)$ and $v_{r,i}(t+T)]$ and the drop-out $[f_{r,i}(t+T)]$, coefficients were based on the study patterns of two gymnasium cohorts, of 1951 and 1958. On the basis of this information, a study profile for each educational process was drawn(1).

The transition coefficient, i.e. the coefficient for transition among the educational processes in the non-restrictive field of studies $m_{r,s}(t+T)$, is assumed to be equal to zero, since insufficient information was available to estimate a numerical value.

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(1) For the results of the study patterns, see Eva Birkeland, op cit., pp. 29-122.

The following two assumptions were made regarding the distribution coefficient, $\nu_r(t+T)$, i.e. the coefficient which distributes the students who have not been admitted into the educational process of their first choice to the educational process of their second choice in the non-restricted field. First, that secondary admissions take place only in social and natural sciences. Second, the value of the distribution coefficients was assumed to be proportional to the primary admissions to those fields where secondary admission is taking place. In other words, if in year t+T in, say, the natural sciences, where secondary admission is taking place, the number of students that had chosen the natural sciences as their first choice and had been admitted (primary admission) was $N_p(t+T)$, the number of secondary admissions $N_s(t+T)$ would be $N_s(t+T) = \nu N_p(t+T)$; ν was calculated as a ratio of primary and secondary admissions $\left(\nu = \frac{N_s}{N_p}\right)$ from the past data and was kept constant throughout the forecasting period. It is true that the above two assumptions simplify the calculations but they are not likely to be realistic. Secondary admissions take place only when the number of the admission seekers to an educational process in the restricted field is greater than the corresponding places (capacity) in that process. This means that we do not necessarily expect to have secondary admission to the various processes in the non-restricted field every year. The distribution coefficient, however, will always reflect the particular situation that had existed in the past years. This will certainly have a serious effect in showing the changes in the students' demand for the various educational processes vis-à-vis the changes brought about in the capacity of the various university departments in order to satisfy this demand. This is especially true when the calculation of admissions to the basic courses in the non-restricted field of study is made by using alternative II, where secondary admissions are considered because of bottlenecks in the system. The effect of the assumptions about the secondary admissions is shown clearly in Table 1 of the present paper. The distribution coefficients, therefore, could become helpful indicators for the direction of the educational system's expansion.

Two of the most crucial coefficients in the model are certainly the total study propensity $[\bar{s}\,(t+T)]$ which shows the number of gymnasium graduates in any year who would like to pursue post-secondary studies and the particular study propensities $[\bar{a}_r\,(t+T)]$ which show the desire of the gymnasium graduates to pursue studies in the various educational processes. These two coefficients are discussed below in the light of the results of the five numerical examples that have been calculated using the model.

As was mentioned before, in four of the examples the total study propensity was assumed to be .50 i.e. 50 per cent of the gymnasium graduates demand post-secondary education each year. In the fifth example, the total study propensity from .50 was increased to .60 during the period 1966-1975 and was kept constant at the .60 per cent thereafter (until 1985). We are not aware of how the model-builders chose these figures. It is very unlikely, however, that the total study propensity would be constant during such a long period (1966-1985) or even in the shorter period of 1975-1985. A study of past trends may perhaps indicate future values of the total study propensity. But we should not attach too much confidence to it because the educational system of our rapidly changing societies is in a highly dynamic state. More and more gymnasium graduates demand higher education every year, something which suggests that the value of the total propensity will change continuously and drastically in the years to come. The effect of a change of the value of the total propensity on the model's results can be shown by comparing the results produced in two of the numerical examples where the only parameter that was changed was the total propensity. We compare the results for the year 1975 in both examples. Here we take the total propensity to be .50 in the one example and .60 in the second. The results for the total number of students in the non-restricted field (the number of students in the restricted field are the same since their calculation is based on the capacity of that field each year), as well as in the various educational processes, are shown in Table VII.1.

From Table VII.1 we see that the percentage change in the total number of students in the entire field is as big as the percentage change in the total propensity coefficient (20 per cent). This is not, however, the case for the particular educational processes. The changes here vary from zero to 51 per cent. This is due mostly to the assumptions made about the secondary admissions, already discussed. And, if we relaxed both these assumptions (i.e. that the secondary admissions take place only in the natural and social sciences and that the value of the distribution coefficients is proportional to the primary admissions to that field), still the proportional changes in the various educational processes would not be equal to the proportional change of the total number of students, i.e. the proportional change of the total study propensity. This then suggests that a small percentage change in the total propensity may bring about a much greater percentage change in the number of students in some educational processes which, if not taken into account, may lead to highly unrealistic results.

To discuss the effects of changes in the values of the particular study propensities, $a_r(t+T)$, we used two of the numerical examples in which these coefficients have been altered. The changes that were brought about to the coefficients are shown on page 15 of the present report, while the results produced by the model in two numerical examples are shown in Table VII.2. From this table, we see that small changes in the values of the particular study propensities bring about considerable changes in enrolment every year. Thus, for example, by increasing the particular study propensity for sociology from .3 per cent to 2 per cent, the total number of students in sociology increased by 346 per cent. Similarly, by increasing the particular study propensity for political sciences from .6 per cent to 2 per cent, the total number of students in political science increased by 123 per cent. The above shows how sensitive the results are to changes in the particular study propensities. From this it is clear that any hypothesis about constancy of the values of the particular study propensities is very likely to affect strongly the results of the models, even if the actual changes are rather small. On the contrary, however, one expects the particular study propensities, especially for some educational processes, to change rapidly and considerably because of rapidly changing labour market conditions as well as student tastes.

TABLE VII.1

COMPARISON OF DIFFERENT RESULTS DUE TO CHANGES IN THE TOTAL STUDY PROPENSITY - 1975

Enrolments / Field	Example 3 Alternative II	Example 4 Alternative II	Difference	% Change
Humanities	13,240	12,660	580	4
Law	3,668	3,668	0	0
Theology	907	907	0	0
Natural Science	12,057	8,651	3,406	39
Economics	2,440	1,701	739	43
Psychology	1,818	1,278	546	43
Pedagogy	570	376	194	51
Sociology	308	217	91	42
Political Science	668	478	190	40
Total	35,676	29,930	5,746	19

TABLE VII.2

COMPARISON OF DIFFERENT RESULTS DUE TO CHANGES IN THE PARTICULAR STUDY PROPENSITIES - 1975

Enrolments / Field	Numerical Example 1 Alternative I	Numerical Example 2 Alternative I	Difference	% Change	Change in the co-efficients
Humanities	12,152	9,788	2,364	24	6.3
Law	3,499	3,499	0	0	0.
Theology	859	859	0	0	0.
Natural Sciences	8,919	8,882	37	0	0.
Economics	1,712	2,180	468	27	1.0
Psychology	1,258	1,718	460	36	1.0
Pedagogy	360	653	293	81	1.2
Sociology	215	959	744	346	1.7
Political Science	484	1,082	598	123	1.4

Source: For the results of the numerical examples, see Eva Birkeland, op. cit., pp. 10, 13.

2. A MODEL FOR THE EDUCATIONAL SYSTEM OF THE FEDERAL REPUBLIC OF GERMANY* (30)

The AfeB (Arbeitsgruppe für empirische Bildungsforschung, Heidelberg) has presently completed the first version of a simulation model for educational systems and applied it to the educational system of the Federal Republic of Germany. The total model comprises the entire field of education from pre-primary schools to the universities and shows their inter-dependencies. It can be used as a quantitative decision tool for the evaluation of strategies in educational policy. Due to the complex structure of the model and the length of the forecasting period, it was necessary to use an electronic computer for data-processing.

The Structure of the Model

The core of the model is a student flow model, which represents the movement of pupils and students through the educational system. The results of this model, that is the supply of pupils and students per period, flow into a teacher model, a space model and a finance model.

For each year of the forecasting period, the teacher model provides balances for teachers of different categories. Within the framework of the space model the demand for space and investment requirements for education are calculated.

The results of the flow model, the teacher model and the space model are entered into the finance model from which financial consequences of alternative assumptions of educational policy become evident.

Figure VII.3 shows the structure of the model. For the teacher model and the finance model, the steps of computing result in balances which - if they show surpluses or deficits - one can try to compensate for in the next run. Thus, the model takes into account feedbacks between results and assumptions. Feedbacks are calculated partly by hand and partly by computer algorithms.

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* This case study was prepared by Professor C.C. von Weizsäcker and Dr. K. Schweikert at our request. It summarises a simulation model developed by the AfeB. More detailed information is given in W. Konrad, H. Kurth, K.U. Oh, W. Sutter, H. Vollet und C.C. von Weizsäcker. "Simulationsmodell für Bildungssysteme - angewendet auf das Bildungswesen der Bundesrepublik Deutschland", in Diskussionsbeiträge, Vol. 6, December, 1971. In addition, the results of longitudinal surveys for the elaboration of transition proportions are presented in this study.

The Flow Model

In the flow model, the supply of pupils and students or school leavers per year of the forecasting period is computed with the help of demographic data and transitions proportions.

Let B denote the supply vector of students, Z the vector of the newcomers, Q the matrix of transition proportions q_{ij} and A the vector of school leavers. Then, the vectors B(t) of student* supply and A(t) of school leavers for all t of the forecasting period can be computed by the equation system:

$$\begin{pmatrix} B\ (t+1) \\ A\ (t) \end{pmatrix} = Q\ (t) \begin{pmatrix} B\ (t) \\ Z\ (t) \end{pmatrix}$$

The flow model works at three levels of aggregation. The first level uses a disaggregated classification of the educational system with about 400 poles for supply and school leaving, the second level represents an aggregated system with about 130 poles and the third level allows disaggregated calculations for the years 1968 to 1980 and aggregated calculations for the years 1981 to 1990.

The aggregations show that it becomes increasingly difficult to make detailed statements about prospective developments with the increase of length of the forecasting period.

The model works on each level of aggregation with only one classification of the educational system. This classification includes the actual as well as the future reformed structure of the educational system, as it is derived from the different blueprints for the Bildungsgesamtplan and the recommendations of the Wissenschaftsrat and the Deutscher Bildungsrat(1).

The transition proportions are variable over time. That is, interpolations and accommodation calculations are carried through by use of the computer programme. When, for example, a transition proportion is changed, the remaining proportions with the same index of origin pole (row) are automatically changed proportionally, so that the condition of consistency:

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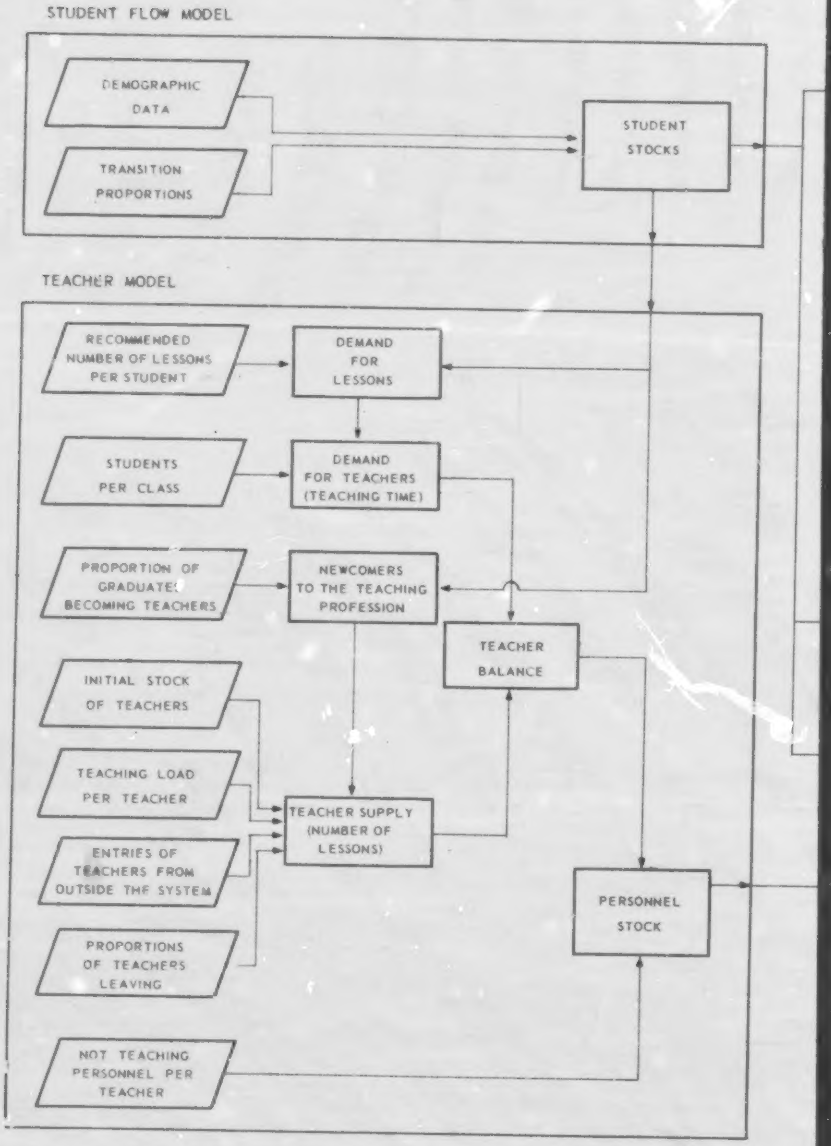
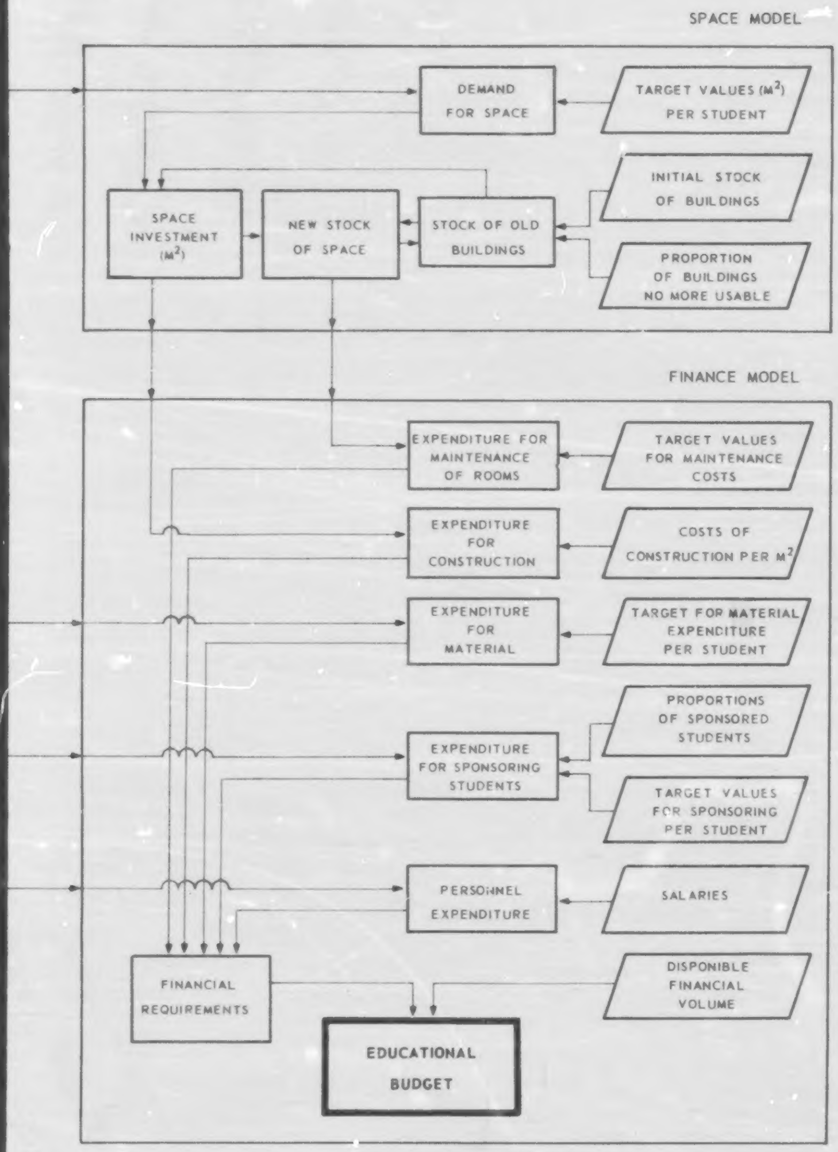
* Here, and in the following text, the term "student" includes pupils.

1) An earlier simulation model has been elaborated by a team of Prognos, Fides and the AfeB for the Bundesministerium für Bildung und Wissenschaft, which uses an actual and a reformed structure simultaneously. The method of a parallel use of the structures, however, requires significantly greater storage capacity.

Figure VII.3. THE STRUCTURE OF THE MODEL


STUDENT FLOW MODEL
DEMOGRAPHIC DATA
TRANSITION PROPORTIONS
STUDENT STOCKS
TEACHER MODEL
RECOMMENDED NUMBER OF LESSONS PER STUDENT
DEMAND FOR LESSONS
STUDENTS PER CLASS
DEMAND FOR TEACHERS (TEACHING TIME)
PROPORTION OF GRADUATES BECOMING TEACHERS
NEWCOMERS TO THE TEACHING PROFESSION
TEACHER BALANCE
INITIAL STOCK OF TEACHERS
TEACHING LOAD PER TEACHER
ENTRIES OF TEACHERS FROM OUTSIDE THE SYSTEM
PROPORTIONS OF TEACHERS LEAVING
TEACHER SUPPLY (NUMBER OF LESSONS)
PERSONNEL STOCK
NOT TEACHING PERSONNEL PER TEACHER


SPACE MODEL
DEMAND FOR SPACE
TARGET VALUES (M^2) PER STUDENT
INITIAL STOCK OF BUILDINGS
SPACE INVESTMENT (M^2)
NEW STOCK OF SPACE
STOCK OF OLD BUILDINGS
PROPORTION OF BUILDINGS NO MORE USABLE
FINANCE MODEL
EXPENDITURE FOR MAINTENANCE OF ROOMS
TARGET VALUES FOR MAINTENANCE COSTS
EXPENDITURE FOR CONSTRUCTION
COSTS OF CONSTRUCTION PER M^2
EXPENDITURE FOR MATERIAL
TARGET FOR MATERIAL EXPENDITURE PER STUDENT
PROPORTIONS OF SPONSORED STUDENTS
EXPENDITURE FOR SPONSORING STUDENTS
TARGET VALUES FOR SPONSORING PER STUDENT
PERSONNEL EXPENDITURE
SALARIES
DISPONIBLE FINANCIAL VOLUME
FINANCIAL REQUIREMENTS
EDUCATIONAL BUDGET

$$\sum_j q_{ij} = 1 \quad \text{is fulfilled for all } i \text{ rows}$$

If a transition proportion is determined for two periods t and t+n, the programme interpolates the transition proportions of the intermediate years linearly.

The calculations within the flow model are started by using a basic matrix of transition proportions (matrix at time t_0). For the following years, either constant or variable transition proportions can be applied. The use of a variable structure is required because the transition proportions vary over time when target values are given which affect the transition coefficient. A matrix of transition proportions, which were set up empirically, was used as a basic matrix for computing the alternatives right up to the present date(1).

Before using the transition proportions in the basic matrix, however, some corrections must be made. Student stocks estimated with the help of transition proportions ascertained by the AfeB in a sample survey in Baden-Württemberg deviated from those of the official statistics. In the first run, the transition proportions for Baden-Württemberg had to be modified, therefore, in such a way that the modified proportions deviated from the non-modified ones as little as possible and the constraint of equality of the estimated stocks with those of the official statistics was fulfilled. The problem was solved by the computer using linear programming methods. In the second run, the same procedure was applied to transition proportions ascertained in the first run for the adaptation to student stocks for the Federal Republic of Germany presented by the official statistics.

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1) For the university area, the AfeB did not use so-called promotion proportions, as they did elaborating the "Dynamisches Strukturmodell". (See Prognos-Fides-AfeB: Dynamisches Strukturmodell für das Bildungswesen der Bundesrepublik Deutschland, Band 2, S.51 f.) Promotion proportions are - in contrast to transition proportions - not subject to the condition of consistency. When varying promotion proportions, inter-dependencies are not automatically taken into account.

A number of further samples enabled the AfeB to state the trends in transition proportions in time-series. First controls of the material allow the conclusion that the basic matrix used up to now does not sufficiently reflect the desire for more qualified education which is revealed by the data. The time series shows a distinct increase of the transition proportions for the initial forms of school types with a higher level. Moreover, the basic matrix is influenced by the alteration in the beginning of the school year which took place in 1966. The shortened school years which thus became necessary had, in our opinion, this effect on the transition proportions: initially, pupils could move into higher classes for they were judged very mildly by the teachers, but then they failed in the next form.

The Teacher Model

The demand for teachers is calculated for 18 categories of teachers in the following way: the stocks of students are multiplied with the recommended number of lessons per student and subject and the result is divided by the class size. From this the demand of teachers' lessons is derived. To determine the demand for teachers expressed in number of persons, it is divided by the mean teaching load per teacher. The supply of teachers is constantly enlarged by graduates from universities, the stocks of these graduates being forecast by the flow model. For the supply model of teachers, the teachers are classified according to age, as the entry and leaving proportions are age-specific. An automatic device for correcting disequilibria of the teacher balance is built within the teacher model, which affects increased leavings (entries) exactly where the balance shows surpluses (deficits).

The Space Model

The space model calculates the demand for space in square metres. The model does not determine the supply of space. The assumption is that the increase of space in one period is equal to the difference between space stock at the beginning and space demand at the end of the period. This takes into consideration the fact that the space supply is provided by a sector external to the educational system and that the building of schools and universities is too small a part of the building sector for bottlenecks in the capacity of the building industry to be significant.

The Finance Model

The stock values of the flow model, teacher model and space model are entered into the finance model. They are multiplied with typical values with respect to target values for different types of costs. From this result - summarised over the components - the total costs of the educational system are obtained. The total costs are confronted with the financial volume, which is derived (exogenously) from the proportion of expenditure for education in the GNP.

Further Development of the Model

a) Refinement of the classification. The model will be refined by the incorporation of student flows which are specific for states (Länder), regions and social strata. Here again, we shall build on data surveyed for Baden-Württemberg. Presently a team of the AfeB is constructing such a model for Baden-Württemberg. It will probably help us to analyse more efficiently the problem of equality of educational opportunity.

b) Aggregation. The more complex the information which the model can provide becomes, the more it becomes necessary to enlarge the system of models and programmes in such a way that the model can be computed on different levels of aggregation and for different types of disaggregation. In this way, the throughput time could be reduced.

c) Consistent adaptation to other models. The AfeB wants to develop a general computer oriented procedure applied to stocks and target values relevant for the model, as well as models for the labour market, etc.

d) Enlargement of the model. The enlargement of the model beyond the national area - e.g. to a model of the educational system that comprises the countries of the Common Market - is especially interesting. An enlargement of the model by including the market for qualified manpower is also planned.

3. MODELS WITH BEHAVIOURAL RELATIONS

Below is a description of each of nine models, all characterised by student behavioural relations. A summary of the variables found in each model grouped by type for comparative purposes is given at the end of this section. The dependent variable for each of these models is some kind of student flow or enrolment ratio. The other variables are grouped by the area of the environment which influences the student behaviour and are listed roughly in the chronological order in which they affect the student during his lifetime. First are the family and personal characteristics which have their impact in the pre-school period and throughout the school period. Second are the other student characteristics, notably measures of previous performance or aptitude, attitudes and aspirations and any special attributes of the student role such as whether he boards at the school or not, extra curricular activities, etc. Third come community characteristics which also affect the student at all periods of his life and which may also affect the supply of education to him. Fourth and fifth are the characteristics of the school proper, which affect the student's behaviour during the educational period of course, and which also affect both his behaviour and the supply of education to him. The sixth group of variables are economic forces such as the cost of education and the pull of the alternative of working which affect his decision on whether or not to continue education after the age of compulsory schooling. Finally comes time (or lagged dependent variables) and a miscellaneous category. The time category goes back to the extrapolation models, all of which have only a single independent time variable. No attempt has been made to further group these variables as to whether they are policy variables or not, supply or demand variables, etc. because it has been found in practice that each of the models defines these differently.

The Girard Model (36)

This is a French study which follows a cohort of some 17,000 students between 1962 and 1966(1).

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1) See Alain Girard and Henri Bastide, "Orientation et sélection scolaire", Population, Vol. 24, N° 1 (janvier-février 1969) pp. 9-46 and N° 2 (mars-avril 1969) pp. 195-261.

The sample was chosen from among those students who passed from the 7ème (end of primary school) into the 6ème (first cycle of secondary school - normally taking place at age 11) between June and September, 1962. It traces their movement year by year during the subsequent five years and will probably continue in the future. A student who makes normal progress in the academic stream should have arrived at the 2ème in a lycée by the end of the observation period. Of this cohort of students, 33 per cent were at work by 1966-1967, 4 per cent were behind by two or more classes, 23 per cent were behind by one class, 22 per cent were in vocational training and probably behind by one or more classes. Only 18 per cent were in the 2ème of the lycée.

The model is descriptive and shows the progress of students classified by sex, socio-professional category of the father, size of the urban area, the programme chosen and the type of school through which the student passed during the period, the age (birth date) of the student as an indication of previous retardation, whether the student had repeated the 7ème before entering the 6ème and the teacher's judgement as to the student's performance in the 7ème. It does not use any formal econometric technique but merely shows the progress of students in each category with one two-way classification by age and performance in the 7ème.

The author warns against extending the results of this study to later cohorts given the various rapid changes which are occurring in the educational system and particularly the rural urban migration and the increasing demand for education by all socio-professional categories. It finds, in general, that girls are less likely than boys to be retarded and that urban concentration is favourable to scholastic success. However, the principal finding is that early retardation is likely to cause later retardation and therefore that students who repeated the 7ème, who did not do well in the 7ème, or who were past the normal age by the time of their entry into the 6ème are less likely to make normal progress later. Both the socio-professional milieu and the orientation chosen at the beginning of the 6ème are correlated with the rate of progress, but also tend to be associated with early retardation so that it is difficult to identify which are causal.

The model is descriptive and is designed to show what factors are associated with retardation of a particular cohort. It might potentially be used for forecasting if there is some reason to believe that the relationship between the progress of children and the other factors will continue over time. It does not include any policy variables and therefore cannot be used directly for policy formulation.

The Tanguy Model (35)

This is also a French model, which seeks to explain differences in enrolment rates between départements for the lower secondary cycle (6ème to 3ème: ages 11 to 14), with special attention to six streams [classique I, moderne I (long) moderne II (court), moderne non différencié, classes d'accueil, classes pratiques ou autres] by public or private control, age and sex for the 4ème and the 3ème. A 1959 reform envisaged extending the compulsory school age first to age 15 and then to age 16, with application of the reform to be completed by 1972. This study then attempts to explain differences in the speed of applying this reform in different départements.

This study is based primarily on a questionnaire sent to students' parents in which information was gathered on the personal characteristics of the student and his family, including his nationality, sex, age, number of siblings, the mobility of the siblings, the father's occupation and whether he is an employer or not, mother's occupation and the education of both parents, whether the student boards at the school or not and whether he uses school transportation.

The most interesting variables, however, are those which characterise the departments and its social and economic activity. These include the kind of economic activity which dominates the area, with particular emphasis on whether it is primary, secondary or tertiary, the amount and type of urbanisation, the rate of industrial growth, the socio-economic composition of the population, migration rates, average family size, the infant death rate and electoral behaviour.

Finally, two policy variables include the number of student fellowships held by children in the area and whether these are national, departmental or a combination and the number of school places available, including the amount of new construction and the division between federal and local responsibility. It is the existence of these two variables and the possibility of using additional school fellowships and increased federal responsibility for school construction as a method of increasing school enrolment ratios and therefore of speeding the reform, that makes this potentially a policy model.

This model does not have any specific time dimension and it is primarily of interest for the application of the particular reform in question and possibly the distribution of the students among the different streams once they are enrolled. Nevertheless, the use of economic variables and other characteristics of the département may throw some light on the interest shown by different regional and economic groups in extending education and may be helpful in predicting future growth of enrolment rates in non-compulsory levels of schooling as well as the effect of a future increase in the school leaving age. In particular, it may aid in the prediction of specific construction needs by geographical region.

Local Government Operational Research Unit (LGORU) Model (24). [See Local Government Operational Research Unit, *Staying on at School*, Report No. C18, May, 1967]. This is a study which attempts to find factors that will explain the percentage of students who stay on at secondary modern schools to age 16 and in grammar schools to ages 16, 17 and 18. It uses a set of data from 96 secondary modern schools and 54 grammar schools in Monmouth County in the United Kingdom for 1964 to 1966. A preliminary study based on interviews with school principles found that it was frequently difficult to predict the rate of staying on on the basis of student plans in the spring, since students often changed their minds in the middle of the summer depending on whether they found jobs or not and what their friends decided to do.

The explanatory variables in the model fall into three main groups: (i) characteristics of the neighbourhood served by the school including the size and age-composition of the population, the socio-economic composition of the population, the proportion of owner-occupied homes and the average size of household; (ii) characteristics of the school environment and organisation including the size of the school, the amount of space available, the rate of staff turnover, the age of the school buildings, the number of full-time staff and a measure of "material environment" based on the laboratory, library and sports facilities and the number of practical subjects taught; (iii) aspects of curricular and employment pressure: including national and county exam results at "O" and "A" level and for various vocational certificates and the number of pupils from the area going to colleges of further education in previous years. A measure of the availability of employment was desired but no satisfactory measures were found.

In order to reduce multicollinearity (and increase the number of degrees of freedom) the number of variables was reduced and only those which contributed significantly to variance and are relatively easy to update annually were retained. For the percentage of 15 year-olds in secondary modern school in year n-1 who remain in school at age 16 in year n (dependent variable 1) the explanatory variables retained were the lagged dependent variable, the material environment of the school and the average size of household, which together gave an R^2 of .75. For the percentage of 15 year-olds in grammar school in year n-1 who remained to 16 in year n (dependent variable 2) the variables retained were the material environment of the school, the rate of staff turnover one year previously, the age of the school buildings and the proportion of GCE successes one year earlier to give an R^2 of .70. The percentage of grammar school 15 year-olds in year n-2 who remained to age 17 in year n (dependent variable 3) was found to depend on the proportion of 15 year olds in year n-2 who stayed to 16 in year n-1 and the proportion of 15 year-olds in year n-3 who stayed to age 17 in year n-1 (dependent variables 2 and 3 lagged one year), with an R^2 of .84. The percentage of 15 year-olds in grammar school in year n-3 who stay to 18 in year n (dependent variable 4) was also found to depend on itself lagged one year plus the rate of staff turnover in year n-1, with an R^2 of .81.

This model can be said to be mainly predictive since it is primarily concerned with finding "explanatory" variables which are sufficiently correlated with the dependent variables to be fairly reliable in predicting them. In fact, the number of initial variables - 61 in toto of which perhaps 40 are applicable to any given dependent variable - compared with the number of observations, suggests that perhaps even the fairly high R^2 are largely fortuitous since with a sufficient number of variables one is always likely to find some which are highly correlated by chance. In any case, the finding that lagged dependent variables were often the most successful predictive variables suggests that perhaps a time-extrapolative model might be nearly as reliable and easier to apply than the behavioural model. Both the material environment of the school and the rate of staff turnover - which are found to be of some significance - are potential policy variables, however.

The Orr Model (3)

This model attempts to measure the dependence of transition proportions in the upper level of British secondary schools on socio-economic factors and is based on data from the National Survey of Health and Development under the directorship of Dr. J.W.B. Douglas. The survey follows a cohort of children born during one week in 1946 through school and into employment. A number of different transition proportions are used as dependent variables in the model including:

i) the highest qualifications attained: no "O" levels, one to five "O" levels, one "A" level, two or more "A" levels, entry to higher education;
ii) whether the student left school at 15 or stayed on;
iii) whether children took six or more or less than six "O" level examinations;
iv) whether students passed two or more, or less than two "A" level exams;
v) whether students entered higher education or not;
vi) science or non-science specialisation at "O" level; and
vii) inclusion of one or more science subject in "A" level exams.

Independent variables include:

i) sex;
ii) type of school: grammar, direct grant, secondary modern, comprehensive, independent, other or unknown;
iii) scores on an achievement examination at age 15;
iv) social class divided as to middle or working class;
v) family size;
vi) school type by boys, girls, or coed;
vii) pupil/teacher ratios;
viii) teacher quality as measured by the percentage who are university graduates;
ix) the per cent in the school who stayed on after age 15;
x) school size;

xi) urban or rural location of the school;
xii) the number of science subjects taken at the "O" level.

The model is based on analysis of variance using a computer technique in which the computer selects sequentially the independent variable which accounts for the largest amount of variance in the dependent variable and also divides the possible values of the independent variable into two groups (if there are more than two possible values) so that the intergroup sum of squares is maximised. For the highest educational level attained (dependent variable 1), for example, the computer found that the variable which explained the most variance was the type of school. One group of selective schools including grammar, direct grant and independent had a mean value of 2.0 when the highest qualification attained was rated on a scale of zero to five - 2.0 corresponds therefore to an average attainment of six or more "O" levels - and the other group of non-selective schools, including secondary modern, comprehensive, other and unknown, had a mean value of 0.1 or virtually no "O" level attempts. It is the computer which divided the kinds of schools into groups and the fact that the groups happened to correspond to selective and non-selective schools is an indication of the meaningfulness of the analysis.

At each step of the analysis the computer chooses within each group the next most important variable for explaining variance and divides it into two groups as long as some variable explains a minimum level of variance. For selective schools the next most important variable was student ability, followed by social class for both ability groups, and then by the sex composition of the school, the per cent of teacher graduates and again the school type for the various social classes and ability groupings. For non-selective schools, ability was also the next most important variable, followed by a further division of school types into comprehensive and unknown versus secondary modern and other for the higher ability group only. The total explained sum of squares in this example was 56 per cent of the total sum of squares. The branches terminate at different points because for any given group none of the remaining variables explained a significant amount of variance or the sample size became too small. Such a procedure was applied to each possible dependent variable except that at some of the higher levels of education, the sample was too small to do meaningful analysis of variance of this kind.

This method of analysing variance was chosen in part to get around the usual problem of deciding in what order to enter variables in a multiple regression equation since the amount of explanatory power assigned to each variable depends on the order in which they are entered if there is multicollinearity between them. This method allows the computer to make an objective decision in that it orders the variables by the amount of variance which they explain. However, this does not really solve the problem of multicollinearity in the sense of giving any more information about causal relationships. If two independent variables are strongly correlated and one is chosen because it explains slightly more variance than the other, the other variable is likely to explain very little of the remaining variance, although there may be more reason to believe that it is a causal variable from external evidence. For example, although common sense would indicate that attendance at a selective school should have a strong influence on the highest qualification students are likely to attain, this is not because the schools are necessarily better but precisely because the students have been selected. It is interesting that within both the selective and non-selective school groupings the ability test score is the second most important variable despite undoubtedly strong multicollinearity between this variable and the type of school.

The methodology used would indicate that this is a predictive model in the classification used rather than a descriptive model in that it is trying to find the variables with the best statistical correlation without necessarily paying attention to any underlying causal relationships. Nevertheless, the description of the purpose of the model would indicate that it is trying rather to be descriptive and eventually to isolate potential policy variables such as, for example, teacher qualifications, teacher/pupil ratios and perhaps even selectivity of schools. In any case this is a small part of a large scale educational planning model which hopes to introduce feedback mechanisms in student forecasting in order to take account of constantly changing forces which influence student numbers.

The data used by the model cover only one cohort of children and therefore do not measure changes over time in the strength of the relationships between dependent and independent variables. It could be used to forecast changes in student flows over time to the extent that these changes are due to shifts in the composition of the student body or the characteristics of the schools they attend.

The Barnard Model (37)

This is also an English study, directed by Professor G.A. Barnard at the University of Essex in association with the Royal Statistical Society, on "factors influencing choice in higher education". It is based on the results of a survey among sixth formers on their plans to enter higher education, as well as their past educational history and personal characteristics. A follow up a half year later investigated whether their plans had actually materialised.

The transition parameters measured include results in "O" and "A" level examinations and movement from the sixth form into a university, college of education, other further education into employment, back to the sixth form, or other. Independent variables include a number of family characteristics including age, sex, the number and educational attainment of siblings, the educational attainment and occupation of parents; student attitudes toward school including their favourite subjects, their satisfaction with schooling and their future career. residence and educational plans; specific course preparation for "O" and "A" level exams and the results; the student's view as to who most influenced his future aspirations; and various characteristics of the schools such as the type and size of the schools, teacher numbers, experience and education, the range of subjects offered at the school, counselling arrangements, etc.

This model is descriptive with a primary emphasis on trying to discover how school preparation and organisation influence the choices of the student and his success at the higher levels of secondary school and in entering higher education. One specific question of interest is why there are so few applicants for university places in science. The model does not have any specific policy variables and the statistical methodology had not yet been decided upon at the time of the interview. It, too, deals with a single cohort and therefore does not have any specific time dimension, but it should help to answer various questions about the effect of secondary reforms on the number and kind of applications to higher education. In particular, it might indicate what reforms in the organisation of course work as early as age 13 or 14 might help to increase both the number of science applicants to university and the general flexibility of students in choosing higher education programmes.

The Perl Model (34)

This is an American model, based on the Project Talent data, which follows a cohort of students from the ninth grade in 1959 through high school, into and through higher education or employment. The model attempts to determine the impact of both college and high school educational resources, as well as of student high school performance and family background characteristics, on success rates of students in college. It is of particular interest methodologically because it is formulated as a set of four simultaneous educational production functions in which high school aptitude, achievement and grades - which are themselves functions of student background characteristics and high school resource inputs - are inputs into the college production function along with college resource inputs. It is intended to be used for a number of policy problems such as how best to allocate resources to high schools and colleges in order to achieve a given desired rate of success in colleges of different kinds, or how to select students for admission into colleges and universities in order to best take advantage of resources in these institutions or meet certain objectives of equal opportunity, etc.

The basic equations used are in double logarithmic form and are summarised below. An additional seven equations are included in the model in order to measure the inter-generational impact of education on success rates of children of students and the effects of education on occupation and income, as well as to allow a rate of return to education to be calculated. However, these are largely peripheral to the question discussed here.

College Production Function:

$Y_1 = F_1$ (Y_2, Y_3, Y_4, College Inputs, Miscellaneous)

High School Production Functions:

$Y_2 = F_2$ (Y_4, Parents' Educational Attainment, High School Inputs, Miscellaneous)

$Y_3 = F_3$ (Y_4, Parents' Educational Attainment, Average Aptitude of High School Student Body, Miscellaneous)

$Y_4 = F_4$ (Parents' Educational Attainment, High School Inputs, Miscellaneous).

Dependent variable Y_1 is a dichotomous Markev Chain student flow parameter divided into the following possible categories of outcomes (or degrees of success in higher education):

a) A student once admitted to the university either fails or does not fail;
b) If the student does not fail, he either graduates or does not graduate;
c) If the student graduates, he goes on to graduate school or he does not go on to graduate school.

Dependent variable Y_2 is the student's score on an achievement test administered in high school. Y_3 is the student's average grades in all academic courses in high school. Y_4 is his average score on an academic aptitude test administered in high school.

High school input variables include:

i) the average aptitude of other students in the high school attended by the student;
ii) the number of students in the high school;
iii) the number of teachers in the high school; and
iv) expenditure for maintenance on facilities and equipment.

College input variables include:

i), ii) and iii) the number of full-time faculty in three categories (different quality levels) teaching in the college;
iv) fraction of total college expenditure devoted to organised research;
v) expenditure for maintenance and allowance for depreciation on facilities and equipment in college;
vi) number of students in college;
vii) average aptitude of other students in the college.

Miscellaneous independent variables include the number of hours per week the student worked while in college, whether the student lives at home or on campus, whether the student's mother is gainfully employed or not.

This model is mainly intended to give a criterion for policy decisions about resources and admissions. It could conceivably, however, be used for predicting the success rate in higher education or the demand for graduate education for either an individual school or for higher education in general, as well as for indicating ways of influencing these flows. It is also particularly interesting for its treatment of time in the educational process, indicating the influence of success or progress in one level of the education (high school) on the subsequent level (college) and thus giving a criterion for allocating resources to both levels based on success in the second level only. As such, the theoretical model may be of interest for other countries at other levels of the educational system.

The Hoenack Model (59)

This model(1) attempts to measure the demand for different kinds of higher education as a function of the cost of that education and the income level of students. It was originally prepared in the context of the three tier system of education in the State of California - junior colleges, state colleges and the University of California, each of which, by state law, is obligated to open its doors to a certain proportion of qualified high school graduates - using data on the number of students in each high school graduating class who were eligible to enter the University of California and the number who actually did. It is being extended and revised under the auspices of the United States Office of Education using Project Talent data.

The model first establishes demand functions for entrance into the different kinds of higher education and for specific campuses of the University of California. The independent variables are the attendance cost, including transportation and living costs for students in different areas, foregone earnings, income level of the student's family and tuition costs net of scholarships.

Such demand functions are then to be used by university planners to determine the effect of various tuition and scholarship policies on both the number of students who will choose to attend higher education and the income class composition of these students. Tuition policies are presumably a general instrument which affect all students to some extent although they affect different income groups differently. Scholarship aid is a selective instrument which can be used to aid particular individuals or particular income groups. This kind of analysis can also, presumably, be extended to indicate the different success rates of different income groups in the university as a function of tuition and scholarship aid.

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(1) See Stephen A. Hoenack, Private Demand for Higher Education in California, Office of Analytical Studies, University of California, 1968.

The model actually confronts different possible utility functions of higher education planners in which the total level of enrolment is balanced against more or less egalitarian income class distributions, given a fixed amount of financial resources. The solution of these equations gives rise to non-linear systems in five unknowns which become difficult to solve, even with a computer, for utility functions which are themselves non-linear. This part of the exercise is not necessary, however.

This model is basically a policy model. It can be used to predict the demand for different kinds of higher education over time as a function of the income distribution of the population (or at least of the parents of high school graduates) and the two policy variables, tuition and scholarship aid, provided it is assumed that the behaviour of people with a given level of income will remain the same.

The Panos-Astin Model (58)

This is a model(1) which also attempts to predict the dropout rate from higher education using the data bank of the American Council of Education. The ACE is a research organisation set up by member colleges and universities and its data bank is based on periodic surveys of a large sample of universities and colleges. This particular study is based on a 1961 survey of 127,212 freshmen in 248 colleges and universities, with a follow-up survey in 1965 to which 36,405 students in 246 institutions responded. A non-dropout in this study is defined as a student who has completed at least four years of full-time college work within the four years covered by the survey whether or not he has received a degree.

The model is a multiple, linear regression using a large number of independent variables divided into pre-college inputs and college environment variables. Pre-college inputs include average high school grades, highest educational level expected to be attained, preferred college major and subsequent career, high school extracurricular activities, parents' education and father's occupation, race, religion, sex, size of high school class. College environment variables are divided into:

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(1) See Robert I. Panos and Alexander W. Astin, "Attrition Among College Students" in American Educational Research Journal, Vol. V, No. 1, January, 1968, pp. 57-72.

i) peer environment which includes such things as the prevalence of competitive or co-operative behaviour in the college, habits in the use of libraries and automobiles, musical and art activities dating habits, attitudes towards school rules;

ii) classroom environment which includes such things as the kind and amount of classroom participation, teacher/student relations, the amount of cheating, strictness in grading;

iii) the college image which includes the student's view of the flexibility and the concern of the college for his needs, the amount of faculty permissiveness;

iv) the physical environment; and

v) the administrative environment which includes the kinds of rules and regulations at the college and attitudes towards such things as drinking, protest, cheating.

The results were by and large unsatisfactory. Pre-college inputs were found to account for only 9 per cent of variance and college environment for slightly more with no single outstanding variables. The conclusion drawn was that none of the variables included were effective in predicting drop-outs and that the approach therefore probably needed to be modified to measure educational output in more than one way, to measure other kinds of inputs and to measure possible interactions between independent variables.

Given the very large number of variables used, most of which are qualitative aspects of the particular institution rather than basic resource inputs with a fixed cost, this model should be classified as primarily descriptive. That is, it is interested mainly in finding which of a large number of variables is statistically correlated with perseverance in college. It is surprising that so little variance is explained but not that no single variable stands out.

The O'Brien-Z[illegible]nter Model(122)

This model is intended to investigate the relationship between the number of students in a particular institution who go on to graduate school and various measures of the quality of that institution and the students who attend it. It was done at the United States Office of Education using data from 273 institutions.

The main dependent variable in a linear multiple regression equation is the proportion of seniors in an institution who intend to enter graduate school. Secondary dependent variables are the number of people who received doctorates between 1920 and 1959 or between 1960 and 1966, who did their undergraduate work at a given institution. Independent variables include (E) expenditures per student, (TU) tuition per student, (EN) enrolment or size of the college, (RS) the number of research staff, (ST) the student/teacher ratio, (FA) the proportion of the faculty with a doctorate degree, (PM) the per cent of the student body male, (PTU) and (PTG) the per cent of the undergraduate and graduate student bodies who received degrees in education. Finally (VM) and (MM), the students' scores on verbal and mathematical Scholastic Aptitude Tests are used as measures of student quality.

The conclusions reached were stated as follows:

> "In summary, (1) given a level of ability, a student who attends an institution with higher expenditures per student is more likely to go on to a Ph.D. than one who does not. (2) The continuation to graduate school also depends upon the majors of the students and the type of institutions which they attend. (3) Ability of students plays an important role in explaining the percentage of students going on to graduate school and Ph.D. production. (4) This role is much more important, if coefficients are to be trusted, than expenditures per student. (5) If this finding is to be credited, recruitment of talented students is likely to pay off more than school subsidies."

This model thus comes to a general policy conclusion that admissions policies are more important than school expenditure for determining the demand for graduate education four years later. However, it measures only additional variance explained and not regression coefficients and therefore it does not quantify the impact on the demand for graduate education of increasing per student expenditure, changing student majors, etc. If it can be expected that students will continue to behave in the same way in the future as they have at this point in time, it might be used to predict the demand for entry to graduate education - and perhaps the number of doctoral graduates - as a function of the Scholastic Aptitude Test scores of the students and characteristics of the institutions they attend.

Variables of Student Parameter Behavioural Models
(By Type)

STUDENT PARAMETER VARIABLES

Girard Model

Flows from entry into 6ème to 2ème (ages 11 to 15) by at work, in CET (Collège d'enseignement technique), in CEG (Collège d'enseignement général), in lycée and proportion of those in lycée who are in 2ème.

Tanguy Model

Enrolment ratios for 4ème and 3ème (ages 13 and 14) by département and commune.

LGORU Model

Percentage of 15 year-olds in secondary modern schools who stay to age 16 in the subsequent year.
Percentage of 15 year-olds in grammar schools who stay to ages 16, 17 and 18 in the three subsequent years.

Orr Model

Proportion of students who stay on after age 15.
Proportion of students with no "O" level exams (Ordinary level examination normally taken at about age 15 or 16), five or less "O" levels, six or more "O" levels.
Proportion of students who pass one "A" level exam (Advanced level examinations normally taken at about age 17 or 18), or two or more "A" levels.
Proportion of students who enter a degree course at a university.
Proportion of students who take some science options in "O" and "A" level examinations.

Barnard Model

"A" and "O" level exam results.
Proportion of students who move from the sixth form in the spring to one of the following in the fall:

- back in the sixth form
- work
- a College of Education (teacher preparatory)
- some other full-time college
- a university
- other

Expectations of students in the spring as to where they will be in the fall.

Perl Model

Dichotomous Markov chain divided into the following possible outcomes:

> A student once in the university either fails or does not fail.
> A student who does not fail either gets a degree and graduates or does not graduate.
> A student who does graduate either goes on to graduate school or terminates.

Hoenack Model

Proportion of students in each high school district who are eligible for the University of California.
Proportion of those who are eligible who enter each of the nine university campuses.
Proportion of each high school class who enter two-year junior colleges, four-year state colleges, or some other post-secondary institution.

Panos-Astin Model

Probability of having completed four years of university work four years after entering.

O'Brien-Zinter Model

Percentage of university seniors (students in their last year of university) who plan to go on to graduate school.
The number of people who received doctoral degrees (Ph.D.s between 1920 and 1959, between 1960 and 1966 and between 1920 and 1966 who attended each institution as an undergraduate.

FAMILY AND PERSONAL CHARACTERISTICS

Girard Model

Sex.
Socio-professional category of father.

Tanguy Model

Nationality.
Sex.
Age.
Number of siblings and position of child in family.
The number of siblings who have moved to outside the commune.
Parents' occupation.
Parents' educational attainment.

Orr Model

Sex.
Middle or working class.
Family size.

Barnard Model

Age.
Sex.
Number of siblings.
Siblings' educational attainment.
Parents' educational attainment.
Parents' occupation.

Perl Model

Family income during the time student is in high school and college.
Parents' educational attainment.
Whether student's mother works for pay or not.

Hoenack Model

Median income of families in high school district.

Panos-Astin Model

Marital status.
Ethnic group.
Parents' educational attainment.
Father's occupation.

OTHER STUDENT CHARACTERISTICS

- Previous performance
- Attitudes and aspirations
- Aspects of school role

Girard Model

Whether student repeated 7ème or not.
Teacher's judgement of student's performance in 7ème.
Age (as measure of whether the student had previously repeated).

Tanguy Model

Whether student boards at the school or not.
Whether student uses school transportation or not.
Whether student has a scholarship or not.

Orr Model

Number of science subject courses taken by the student in preparation for "O" level exams.

Barnard Model

Student's favourite subjects before the "O" level.
Student's future plans as to career, education and residence.
Student's satisfaction with schooling.
Courses taken by student in preparation for "O" and "A" level.
Whether student boards at the school.
Successes at the "O" level.

Perl Model

High school aptitude, achievement and grades.
Number of hours per week the student works while in college.
Whether the student lives at home or on campus while in college.

Panos-Astin Model

High school grades.
Career and education plans.

High school student activities.
Choice of major field in college.

O'Brien-Zinter Model

Verbal and Mathematical Scholastic Aptitude Test scores.

COMMUNITY CHARACTERISTICS

Girard Model

Size of urban area or rural.

Tanguy Model

Nature of principal economic activities of area.
Type and number of urban activities.
Growth rate of principal industries in area.
Socio-economic composition of population.
Migration rates.
Average family size.
Infant death rate.
Electoral behaviour.

LGORU Model

Size and age composition of population in school district.
Socio-economic composition of population.
Number of households.
Number of owner-occupied homes.
Average size of household.

Orr Model

Urban or rural location of school.

SCHOOL PHYSICAL RESOURCES

- Type of school
- Number and quality of teachers
- Physical facilities

Girard Model

Programme chosen.
Type of school.

Tanguy Model

Number of places provided in region.

LGORU Model

Size of school.
Material environment.
  - existence of special courses
  - laboratories
  - libraries
  - physical education facilities
Square footage of school.
Age of school.
Pupil/teacher ratio.

Orr Model

Type of school.
Coed or single-sex school.
Pupil/teacher ratio.
Per cent teachers who are university graduates.
School size.

Barnard Model

Type of school.
Size of school.
Teacher numbers and
Teacher quality (experience, education).

Perl Model

Number of faculty in three quality categories.
Proportion of college expenditure on organised research.
Expenditure of college on maintenance and depreciation of physical facilities.
Size of college.
Size of high school.
Teacher/student ratio on high school.
Expenditure on maintenance and depreciation of high school physical facilities.

Panos-Astin Model

Size of high school.
College per-student expenditure.
College faculty/student ratio.
Per cent of faculty with Ph.D.s.
Library size.

O'Brien-Zinter Model

Expenditure per student in college.
Size of college.
Percentage of research staff.
Student/teacher ratio.
Percentage of the faculty with a doctorate.

QUALITATIVE ASPECTS OF SCHOOL ENVIRONMENT

- Curriculum
- Organisation
- Student body characteristics
- Other qualitative aspects

LGORU Model

Rate of staff turnover.

Proportion of eleven-plus examination successes in school four to six years before.

Rates of success in CSE, MCE, "O" and "A" level examinations in previous years.

Percentage of pupils from school in previous years who went on to further education.

Orr Model

Proportion of 15 year-olds in school who stayed on after age 15.

Barnard Model

Range of subjects offered in school.

Counselling facilities.

Perl Model

Average aptitude of other students in college.

Average aptitude of other students in high school.

Panos-Astin Model

"Peer, classroom and administrative environment".

Average ability of other students in college.

O'Brien-Zinter Model

Per cent of student body male.

Percentage of graduate and undergraduate student body taking degrees in education.

ECONOMIC VARIABLES

- Cost of education
- Future earnings
- Job opportunities

Tanguy Model

Number of fellowships available in region.
(See Community Characteristics).

LGORU Model

Would have liked to measure employment opportunities but could not find a systematic measure.

Perl Model

Average annual expenditure of student while in college (excluding tuition).

Hoenack Model

Attendance costs (including transportation).
Foregone earnings.
Subsidies and scholarships.

TIME OR LAGGED DEPENDENT VARIABLES

LGORU Model

Percentage of 15 year-olds in secondary modern and grammar schools who stayed on to ages 16, 17 or 18 in the year preceding the one being estimated.

MISCELLANEOUS VARIABLES

Barnard Model

Student's view of what forces and persons were most influential in helping him to decide his career and educational plans.

Part Three

PROBLEMS AND PURPOSE

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Chapter VIII

POLICY PROBLEMS

1. AN ANALYTICAL FRAMEWORK

The rationale for including this part in the report can be stated in the following terms: one, we wish to determine a set of basic issues underlying educational policies of Member countries as reflected in the replies to an enquiry carried out by the OECD among the national authorities of Member countries; two, we wish to examine the extent to which the basic issues of educational policies identified can in fact be matched with the purpose and application of the more than one hundred mathematical models of the education sector surveyed in this report. Three, we wish to demonstrate the extent to which mathematical models have succeeded or failed to come to grips with some of the basic issues of educational policy in Member countries and to add to our suggestions concerning the lines along which further work on model-building in countries could be reoriented.

Thus, we are primarily concerned with two questions, namely, the boundary that defines that part of the education sector which falls into the realm of public policy-making, and the extent to which the purposes of the mathematical model-building effort are directed towards the solution of these problems. Each of these two problems will be taken up in this and the following two chapters, respectively. In order systematically to discuss the policy problems of the education sector and relate these to purposes of mathematical models it will be necessary to set up an analytic framework for this discussion. The proposed a priori framework has two advantages. In the first place, this will permit us to look at the specific problems in a perspective provided by the generalised conceptual context. In the second place, the proposed analytic framework will enable us systematically to order our presentation in this and the following chapter.

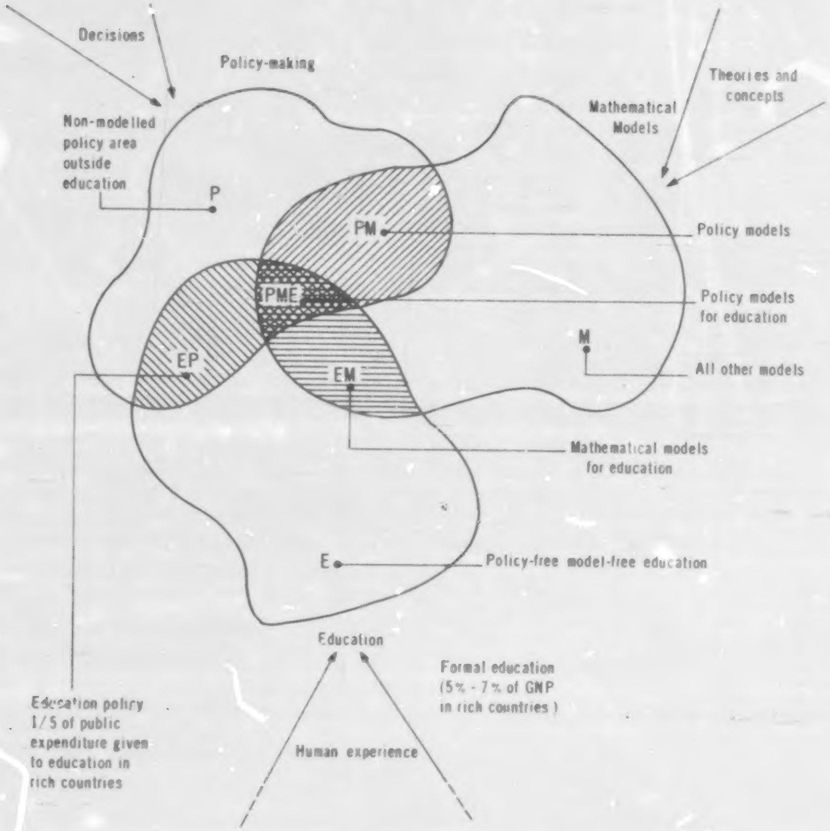
Using a simple diagram (VIII.1) we shall illustrate three sets of subjects, the underlying bases from which they have emerged and the way in which they overlap. The intersection of these sets will provide us with an interesting way of looking at the elements belonging to pairs of these sets. Finally, we shall be able to show that the elements common to all these sets are the major concern for us, namely, those mathematical models (elements of set 1) that have elements of policy-making (set 2) for the education sector (set 3).

The diagram shows three intersecting figures, namely, policy-making, mathematical models and the education sector. The converging (narrowing) arrows associated with each figure indicate the bases from which the corresponding subjects have emerged. As will be demonstrated later, the elements of policy-making arise from a more general notion of human decisions. Similarly, we can see that the mathematical models constitute a special class of objects, which constitute a part of theories and concepts in general. Finally, education itself may be regarded as one of the many human experiences that is experienced during a lifetime.

If we now assume that each of these three bounded areas constitutes a set of elements, we can distinguish seven types of elements in terms of their belonging to one or more of these sets. If we take all policy-making objects, there are those which do not belong to the set that covers objects or mathematical models nor to the set that includes objects in the education sector. This may be called the non-model policy area outside education, (P). Similarly, we can refer to those mathematical models that are neither concerned with policies nor can be classified as belonging to the education sector. These are the residual models outside our area of interest, (M). Also, within the set comprising the education sector we have those objects that are outside the reach of policy and which are not amenable to the application of mathematical models. This may be regarded as policy-free, model-free education (E).

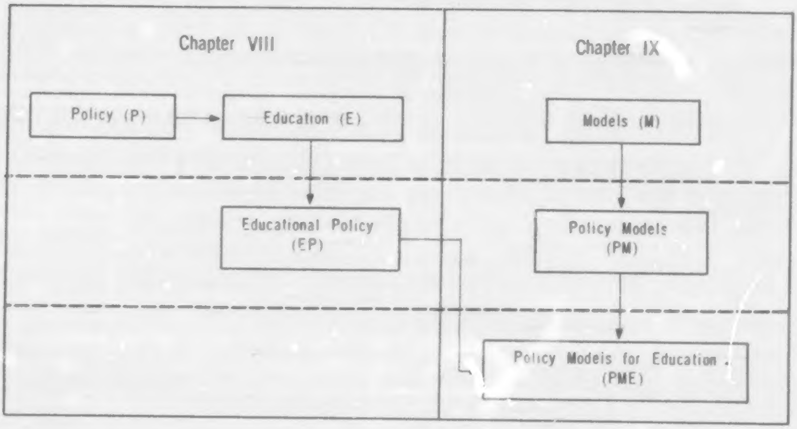
There are a number of objects that may belong to two sets. Objects of policy-making for which mathematical models can be constructed belong to the two corresponding sets and may be regarded as policy models (PM). Similarly, there are mathematical models concerned with the education sector which, as a result, belong to the two corresponding sets and may be called mathematical models for the education sector (EM). These objects constitute the bulk of the present report. Finally the

Figure VIII.1. THE ROLE AND LIMITATIONS OF MATHEMATICAL MODELS FOR MACRO AND MICRO POLICY-MAKING IN EDUCATION


Decisions
Policy-making
Theories and concepts
Mathematical Models
Non-modelled policy area outside education
P
PM
Policy models
PME
Policy models for education
M
All other models
EP
EM
Mathematical models for education
E
Policy-free model-free education
Education
Formal education (5% - 7% of GNP in rich countries)
Education policy 1/5 of public expenditure given to education in rich countries
Human experience

intersection of the set described as the education sector and the set described as policy-making provide elements designated as educational policy (EP). In the last analysis, we have elements that belong to all the three sets and which, as a result, may be called policy models for the education sector (PME) because these objects belong to the policy-making set and to the mathematical models set as well as the set described as the education sector.

This simple delineation shows the interfacing of the policy problems of education with the purposes underlying model-building for the education sector. It will be recalled that at the outset of the report we pointed out that one of the purposes of the survey was to show how to bridge the growing gap between the fast moving developments in model-building technology and the practical application of these models in the area of educational policies which has lagged behind. But before we take up this problem it will be useful to discuss each of the two aspects of the problem separately. The order of presentation in this and the subsequent chapter is illustrated in the following diagram.



In this chapter we shall discuss the meaning and scope of policy-making, followed by the question of the boundary of education and the relationship between policy-making, on the one hand, and the aspects of the education sector covered by public policies, on the other. The following chapter will discuss the role of mathematical models in the formulation of policies and the way in which these models could be brought to bear on the problems of the education sector.

Policy

One of the definitions of the term "policy" given in the Oxford Dictionary is "course of action adopted by government, party, etc....". Such a definition does not reveal the basic nature of policy. Under certain given conditions a decision rule is developed which is expected to be applied under those conditions in order to obtain predictable outcomes. For example, a student in the United Kingdom is to be admitted to an institute of higher education provided that he has passed at least two "A" levels. This decision rule enables admission officers to follow a set policy. The decision rule is more or less automatically applied under identical conditions. It has a repetitive character. It frees the decision-maker from exercising his discretionary powers in each separate case where decision is required. In this sense, policy is the adoption of a more or less automatic decision rule to be applied under certain given conditions ceteris paribus.

Let us contrast this with other decisions which do not have this repetitive character and which require the use of discretionary power in each special case. Following the illustration given above, we may refer to the decision of a college president to close down the institution in, say, a special case of student unrest and thus deny students access to the institution. The character of this decision lies in its quasi-uniqueness. No policy has been established based on any decision rule which would have enabled the president to follow this particular course of action under given conditions. On the contrary, the president exercised his discretionary powers in order to make the decision to close the school. Had a decision rule been formulated enabling the president to apply it under given conditions, then one could speak of a policy under which the president is expected to act.

The above viewpoint leads to the conclusion that policies do not exist for unique events. However, if decisions are continously repeated for a similar set of conditions, then one can expect the emergence of a policy. This may be regarded as an unconscious ex-post hoc formation of policy. On the other hand, a conscious policy may be stipulated ex-ante. The conscious formation of policy results from a deliberate attempt to define alternative courses of action and to provide a basis for choice from among the alternatives, according to certain criteria, which gives rise to a decision rule. An illustration of ex-post policy formulation would be the emergence of rules for granting tenure to academic staff of American universities. On the other hand, an illustration of ex-ante policy formulation is the racial segregation rules formulated by the Supreme Court of the United States and issued as directives to school authorities, or a policy of providing crash courses in universities to meet teacher shortages

Therefore, we can consider policy as a class of decisions for which a rule exists that could be applied, in all similar conditions to a significant problem situation amenable to control or influence. This, admittedly, is a somewhat restricted notion of policy and, in this respect, it differs from the current usage of the term as "an adopted course of action". It will be demonstrated subsequently that the use of the term in the restricted sense will permit us to examine the way in which mathematical models can be used to tackle policy problems in the education sector.

From our definition of policy in terms of a decision rule, it follows that the two traits of a policy are goals and instruments. To give it a quantitative connotation, policy goals are sometimes referred to as target variables, and we shall adopt this term. This implies that these variables are given fixed values the realisation of which becomes the objective of policy. On the other hand, instruments are considered as those variables that are under the control of the policy-makers or are influenced by them in order to achieve the desired values of the target variables. It is through the manipulation of the values of the instrument variables that one could affect the realisation of the target variables(1).

Educational Boundary

Unlike such production sectors as mining or agriculture, it is difficult to define the boundaries of the education sector. Farming is carried out on the farm and mining is carried out in the mine but only formal education may be considered as being carried

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1) Jan Tinbergen, Theory of Economic Policy, North Holland Publishing Co., Rotterdam, 1952.

out in identifiable educational institutions. So-called non-formal education is usually carried out in institutions that cannot be identified as educational. For instance, the whole area of in-service training falls outside the formal education sector. It is nevertheless difficult to accept the notion that the education sector comprises only those institutions that carry out formal education.

The second problem arises from the difficulty of separating out educational influences from non-educational influences on the output of education. Let us assume that we define "output" as the educational achievement of a group of children. In this case, apart from such factors as the initial characteristics of children and the characteristics of the school, there are a host of factors of a socio-economic nature arising from family background, housing and other aspects of socioeconomic environment which may be equally decisive.

Structure

Whatever boundary we define for education we still face the question concerning the structure of education. By the structure of education we mean the channels, types, levels and grades through which the students pass in order to obtain certain qualifications. In addition, we have the organisational hierarchy of different levels of public decision-making for education involving considerations of centralisation and decentralisation as well as regional autonomy. Another aspect of the structure is concerned with the division between the public and private sectors of education, and the related set of questions concerning the financing of education and the bearing of the financial burden. These questions of the structure, or the configuration, together with goal specification of education, belong to the problem of the design of the system. Because of the very nature of such problems, considerations regarding them often take us beyond the limits of the educational boundary.

The problems of the structural design cannot be separated from overall social considerations, assuming an isomorphic relationship between societal objectives and system goals. Take, for example, such concepts as recurrent or permanent education, individualised learning or even comprehensive educational planning; all these arrangements affect the structure of education and are intimately related to overall social and economic considerations that reach beyond the defined educational boundary. The solution to some of these problems must be found by reference to variables outside the education sector since these variables will constitute the environment within which the desired educational arrangements are set up.

Policies for Education

Having given our definition of the term "policy" (and having discussed the question of the boundary of education and its structure), we will turn next to the intersection of policy and education. Education policy can be considered in terms of decision rules applied to the phenomena that fall within the educational boundary. The fact that the decision rule has a repetitive character enables the selection of values of instruments with a view to attaining given educational targets.

In a strict sense, then, educational policy will not be directly concerned with system design and questions of a structural nature involving considerations outside the educational boundary. Educational policy is a more limited concept than the formulation and means of realisation of societal objectives. With this definition of educational policy it will be possible to examine its relationship to mathematical model-building, particularly directed to its application for the education sector. We have already seen that there is a special class of mathematical models for the education sector which is concerned with the problems of educational policy (decision models).

The definitional limitations that we have thus imposed on ourselves enable us to exclude those conceptual approaches such as social systems theory that ambitiously attempt to tackle both the problems that go beyond the educational boundary as well as the problems of the design and redesign of educational systems in terms of societal goals. These considerations have been beyond the scope of mathematical models for the education sector even though specific intersectoral problems have been successfully treated. One cannot even be sure whether future developments in the art of mathematical model-building in education will enable us to tackle the broader problems of system structure and system goals.

Thus, it is useful to distinguish two levels of analysis: at a "higher" level we are interested in examining education as a total system. Here the twin concerns are with the design of the structure of the system and the stipulation of the system's goals.

On a "lower" level, we can study educational policies in accordance with the definition of the concept of policy stated above. Here we are primarily concerned with the relationship between policy instruments, on the one hand, and the realisation of targets on the other. The issues of education can fall into either of the two levels of analysis. There are issues concerning the restructuring or redesigning of the education system in relation to its goals as well as those of society and there are also issues concerned with the formulation of policy and its effective application in order to attain the desired targets. Illustrations of these two types of educational issue are readily available and will be indicated in the next section. In principle, both these types of issues are amenable to the application of mathematical models. However, in the case of the more modest policy issues, one finds that mathematical models are of greater relevance.

2. SYSTEM DESIGN AND POLICY PROBLEMS

We have put forth the viewpoint that the area of intersection between the objects of the education sector, on the one hand, and the objects of policy analysis in general, on the other, can be divided into two kinds. In the first place, we have the problems of structural design and system goals drawing upon generalised frameworks developed in systems theory; and, on the other hand, we have mathematical models with associated quantitative techniques from operations research, econometrics, etc., that are to a great extent concerned with the calibration of policy instruments with desired targets. Between these two high points we have a large territory of no-man's land. What we need here are "bridge concepts" which will, in some sense, relate overall system designs and goals with the specific exercise of using policy instruments for the attainment of given targets.

Policy Sciences

According to the prospectus of the new quarterly journal entitled Policy Sciences that first appeared in 1970, its purpose is "the application of structured rationality, systematic analysis, and interdisciplinary knowledge to problems of public policy". The journal claims that "it will pay close attention to the application of policy science to real decisions, aiming to include the outcome as well as the state-of-the-art and to attract the participation and respect of practitioners". If new knowledge fields and knowledge professions can be developed to fill this gap and occupy the no-man's land just described then this will be a welcome development. It is very possible that the new effort in developing policy sciences may become useful in this respect. Fears to the contrary have also been expressed. There is a genuine danger that the policy sciences may turn out to become "lobby sciences" by refining the art of persuasion and pressure to exert influence on the value systems of the leadership in society and its institutions, while failing to develop and use operational technologies of problem-solving(1).

Also, the emphasis which the new professional group of policy scientists has placed upon interdisciplinarity and the intersectoral viewpoint is salutary if we wish to study the relationships of macro-systems to micro-behaviour. However, if this effort is restricted to the study of macro-behaviour alone, as in the case of policy sciences, then we seriously neglect a number of critical points that should be incorporated in any effort to build what we have described as the bridge concepts. More specifically, we need empirical analyses of micro-behaviour, the results of which could become the building blocks for the construction (or reconstruction) of macro-or intersectoral approaches to public policies in education and elsewhere.

More specific policies of a concrete nature are now being handled by an array of available techniques and mathematical models; this does not preclude a further development in this direction to improve this technology and, particularly, to enhance its practicability. The "practicality gap" of course exists at this level, and a number of suggestions can be made to alleviate this problem. But it is not clear how one can attempt to bridge the gap between specific techniques used to tackle concrete policies and the problems of system design and the specification of systems goals. It will indeed be a welcome development if policy sciences, or any other effort with any other label existing or invented, could be directed towards the problems of setting priorities and goal specification of social systems, together with the formulation of specific policies in terms of instruments and their use in target realisation. The problem is that of external consistency. We will need to develop theories and concepts just before calling in mathematical models to operationalise these theories and concepts. Only then will it be possible to

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1) See Michael Radnor, "Management Sciences and Policy Sciences" in Policy Sciences No. 2, 1971, pp. 447-456.

carry out a detailed and consistent analysis of priorities in which the micro- and macro-elements both play their respective roles. But in the meantime we need empirical insights and approximations to the problem of determining priorities. In the following pages we shall describe two attempts to identify country specific issues of the education sector. The first will be a "theme analysis" that we have used for this part of the report. The other will be a "content analysis" that was a trial experiment to understand its potential use. Both these techniques, the former qualitative in nature and the latter quantitative in nature, were applied to a set of communications from national educational authorities.

3. ANALYSIS OF ISSUES

Theme Analysis

We have divided the issues in education into three types: policy issues (e.g. meeting teacher shortages); structural issues (e.g. re-organisation of universities); and other issues (e.g. improvement of educational data). Rather than set up the inventory of issues on a priori grounds, we have availed ourselves of the opportunity to use readily available empirical information as a basis for constructing the following list. Recently, OECD conducted what has been called a "Growth Enquiry". The questions were addressed to national education authorities and were grouped under five broad headings. (These headings corresponded to the proceedings of the Conference on Policies for Educational Growth that was being planned by the OECD.) These headings were:

A. Educational Goals and Long-term Policies
B. Resources for Educational Growth
C. Strategic Changes in Educational Structures
D. Policies for Research, Development and Innovation
E. Governmental Machinery and the Process of Educational Change.

This Growth Enquiry survey was carried out in early 1970. The replies were prepared by the national education authorities as definitive statements of the governments on the matters noted above.

From the reply of each of the Member countries it was possible to extract a list of ten country-specific issues in each case. These issues were then grouped into the three types of issues just described. Of all the countries put together, we have approximately 200 country-specific issues in education. In a number of cases, as could be expected, two or more countries may have stated the same or similar specific issue.

Through an analysis of the relative emphasis given to different issues and the frequency of their appearance in the different country listings, it is also possible to construct a 10-item list of generic issues. These issues can be described in general terms. For example, one priority issue appears to be the problem of evaluating returns from education using cost/benefit analysis. Another issue is concerned with the future development of the concept of, and arrangements for, "permanent education" through adult education programmes, involving sandwich courses, refresher courses and in-service training. (In conjunction with the concept of permanent education, consideration is also to be given to "recurrent education", meaning post-compulsory education in recurring periods throughout life, rather than following immediately after the completion of secondary education; this involves a new conception of the relationship between education and work as well as the relationship of the two to the leisure or discretionary time of individuals.) But such an exercise will be of little use for detailed analyses of country situations and the applicability of mathematical models to those situations.

In the next few pages, we have given a detailed inventory of educational issues in Member countries, divided into the three types: policy, structural and other. Only the key phrases or sentences have been shown to indicate the main thrust of the theme without the amplifications that would be necessary were each issue analysed separately.

Content Analysis

To illustrate the technique of content analysis as another way of looking at the analyses of issues, we shall report on an experimental exercise carried out in applying content analysis to the communications received from national educational authorities as a result of the Growth Enquiry mentioned above. This analysis was carried out by a private research organisation specialising in economic and social-psychological surveys and investigations

Table VIII.1

INVENTORY OF EDUCATIONAL ISSUES IN MEMBER COUNTRIES

AUSTRIA

POLICY	1. Estimation and measurement of the requirements for university graduates in relation to educational planning and manpower demand.
STRUCTURE	1. Establishment of pre-school classes 2. Teaching of a foreign language from 3rd or 4th grade 3. Establishment of all-day (five days a week) schools 4. Establishment of comprehensive schools (all children, ages 10 to 14) 5. Introduction of wider range of optional subjects in the upper division of secondary schools 6. Reform of school-leaving examination 7. Reform of studies, structures and administration and the reform of teaching and examinations as well as the promotion of science 8. Measures for further study giving due consideration to the results of modern university didactics, the reform of the university institutes, the reform of faculties and university management ensuring the participation of all those involved
OTHER	1. Establishment of a centrally-integrated information system comprising the whole educational system required for economics of education

BELGIUM

POLICY	1. Priority to be given to education expenditure in terms of general public expenditure 2. Problem of financing educational expansion in face of opposition from certain sectors of public opinion 3. Increase in the "return" to education in the sense of a reduction of expenditure on personnel in relation to the number of pupils 4. Rational use and effective control of public funds used by the education sector
STRUCTURE	1. Fundamental reform of secondary school instruction including a comprehensive system of schools and more flexible choice of subjects 2. Reforms of education structures consistent with the expansion of the universities

DENMARK

POLICY	1. Financing of long-term needs of education in connection with perspective educational planning up to 1985 in view of the long-term trend of the public sector as a whole 2. Development of each educational sector according to anticipated future influx of students 3. Improving the utilisation of educational resources 4. Counter-balancing geographically (urban/rural) differences in educational opportunities 5. Limitations to development of the educational system due to the restrictions in the general demand for manpower in the public sector 6. Ensure access to higher education by development of differentiation of possibilities in the upper secondary school and in the courses leading to higher preparatory examinations
STRUCTURE	1. Reform of vocational education and the training of technicians 2. Development of institutions of higher education so as to give greater access, establishment of new universities and the restructuring of studies leading to higher education
OTHER	1. Establishment of an improved quantitative basis for decisions on budgeting and planning in higher education

Table VIII.1

INVENTORY OF EDUCATIONAL ISSUES IN MEMBER COUNTRIES (Contd.)

FINLAND

POLICY	1. Reviewing quantitative targets on enrolment and finance in all sectors of education 2. Shortage of teachers at both secondary and university levels 3. Lack of proper buildings as a bottleneck in the expansion of universities 4. Improvement in the effectiveness of educational expenditure for comprehensive schools by studying the expenditure of different types of schools
STRUCTURE	1. Decentralisation of the school administration to allow a more immediate connection between planning and decision-making 2. Development of a co-ordinated plan for recurrent education 3. Total reform of Finnish school system including the introduction of a twelve-year differentiated comprehensive system
OTHER	1. Experimental pedagogical work and experiments with the comprehensive school as a priority area of educational research 2. Establishment of a centralised system of data collection for the purpose of co-ordinating student allocation among universities 3. National co-ordination of entrance procedures for higher education by developing proper methods through an analysis of the requirements of different fields of study ; standardisation of the selection criteria ; reform of the final examinations of the secondary level and matriculation examination system

FRANCE

POLICY	1. A system of government aid to students at schools and universities, what form, how selected, relevance of family income, etc. 2. Co-ordination of existing action and formulation of new proposals for permanent education 3. Re-examination of the allocation of financing between the State and local authorities with a view to increasing State participation 4. Development of the means of analysis, conception, control and evaluation of the utilisation of educational resources 5. Redressing the balance between the humanities and the sciences to the latter's favour, and greater emphasis on the development of technicians and professionals
STRUCTURE	1. Rational reorganisation of the national administration of education as a prerequisite for the reform and modernisation of the educational system
OTHER	1. Development and co-ordination of educational research as the basis for modernisation of the educational structures 2. Development of a system of permanent comparison of the methods and objectives of educational planning 3. Inadequacy of present statistical apparatus for long-term quantitative and qualitative planning 4. Education technology and evaluation of the educational system

Table VIII.1

INVENTORY OF EDUCATIONAL ISSUES IN MEMBER COUNTRIES (Contd.)

GERMANY

POLICY	1. Overcoming shortage of teachers 2. Methodology of cost-control, cost-effectiveness analysis, and their rational employment of educational facilities and their management 3. Forecasting the qualitative and quantitative development of higher education taking into consideration the reform of curriculum and examinations, research, organisation, trends in numbers of students and the demand for personnel, equipment and investment
STRUCTURE	1. Modernising curricula with regard to efficiency and future needs, equality of opportunity (differentiation, etc.), and the development of a clearly structured curricula for higher education 2. Reform of higher education to cope with expansion 3. Introduction of pre-primary education especially with a view towards equality of opportunity in spite of different social background 4. Development of further (adult) education into a full fourth stage of the education system 5. Reform of vocational education in the interest of mobility of the individual and efficiency of the system 6. Integration of vocational and general education in structure content, level of intellectual achievement and prestige
OTHER	1. Co-ordinated educational planning in a federal State (including the problem of doubling the expenditures on education within a few years)

GREECE

POLICY	1. Development of methods of technical analysis of long-term trends in the educational sector, including an elaboration of statistical data on the educational sector 2. Problem of investment financing in the educational sector 3. Expansion of relevant university departments to ensure a supply of teachers in view of the shortages of teachers in applied sciences 4. Improvement of remuneration to attract the necessary qualified personnel to education
STRUCTURE	1. Teacher-training to be made more comprehensive by modernising existing training courses 2. Introduction of modern technologies in education (e.g. audio-visual methods) 3. Reorganisation and strengthening of lower and intermediate technical education 4. Study leading to the establishment of wider elementary and secondary education centres 5. Reconstruction of educational flows to higher education and their adaptation to the specific needs in each educational sector
OTHER	1. Scientific programming in favour of research and development in education

Table VIII.1

INVENTORY OF EDUCATIONAL ISSUES IN MEMBER COUNTRIES (Contd.)

IRELAND

POLICY	1. Increasing the supply of teachers particularly in the applied sciences 2. Preparation of a social programme providing an integrated picture of demographic, employment, economic and educational forecasting which takes into account changes in population distribution and other social indicators 3. Problem of limitations on the overall proportion of national resources to be devoted to the educational sector 4. Accelerated building programme at all levels of education in view of the projected explosion of numbers participating in full-time education 5. Study on the causes of dropout at the primary level and the solution to this problem
STRUCTURE	1. Reorganisation and expansion of third level education to cope with anticipated growth in enrolments 2. Development of "Leadstart" programmes to deal with socially and culturally disadvantaged children 3. Development of adult retraining programmes and "second chance" education 4. Increased vocational, technical and technological education by introducing Regional Colleges
OTHER	1. Establishment of a planning-programming-budgeting system

ITALY

POLICY	1. Study of the problems of financing education including social contributions to education and student aid, with a view to establishing a system of educational finance 2. Study of the policy of government intervention in the content and methods of instruction to associate more closely the instruction in the sciences with that in the humanities in view of the lack of adequate preparation of personnel
STRUCTURE	1. Reform and expansion of the universities for more effective training of teachers, developing research and increasing the supply of qualified manpower 2. Organise and develop educational research, innovation and development as the basis for the reorganisation of educational structures 3. Improve the quality of teaching by radical changes in the training, information and responsibilities of teachers 4. Creation of a special school system parallel to the existing system which will permit dropouts to continue their studies 5. Reform of upper secondary and post-secondary education to increase the polytechnic nature of basic instruction, thus training more adaptable qualified manpower in the newly developing technological sectors of the economy 6. Programme for the education, re-education and permanent education of adults
OTHER	1. Absence of a systematised means for the long-term (10-15 yrs.) evaluation of the needs of the educational sector 2. Absence of procedures and functional technologies capable of ordering the quantitative and qualitative evolution of education

Table VIII.1

INVENTORY OF EDUCATIONAL ISSUES IN MEMBER COUNTRIES (Contd.)

JAPAN

POLICY	1. Determination of an adequate salary standard for teachers in comparison with those in other fields of professional activity, in order to secure the necessary human resources in the teaching profession 2. Development of personnel policies to improve the professional level of the teachers in elementary and secondary schools 3. Determination of the most effective educational investment to improve school environment 4. Ceiling in the expansion demand for higher education 5. Financial policy regarding public aid to private schools without adverse effects on their spontaneity and independence 6. Investment policies which result in a balance between fundamental research and currently applied research taking into account political considerations
STRUCTURE	1. Balancing the social demand of diversification of upper secondary education and the aspirations of the people for increased opportunity for more advanced education 2. Adoption of the autonomous aims of universities in the course of implementing desirable overall national plans for the reform of higher education 3. Development of a new education for children of pre-school age, learning from the results of educational research
OTHER	1. Study of a planning-programming-budgeting system with a view to its introduction into the ministry of Education

LUXEMBOURG

POLICY	1. Establishment of a middle-term plan for school construction
STRUCTURE	1. Reform of the entire system of technical and professional education 2. Adaptation of secondary education to, and co-ordination with, technical and professional education 3. Improvement of scholastic and professional guidance 4. Development of greater flexibility between different types of education 5. Development of a system of adult education which includes retraining and advanced training of all levels of workers 6. Special education for mentally handicapped children
OTHER	1. Preparation of a plan for innovation in educational methods and reforms in teaching programmes 2. Need for closest co-operation with neighbouring countries at all stages of educational planning

Table VIII.1

INVENTORY OF EDUCATIONAL ISSUES IN MEMBER COUNTRIES (Contd.)

NETHERLANDS

POLICY	1. Future development of the educational system limited by lack of financial resources 2. Shortage of fully qualified academic staff in certain sectors of the university 3. Research into raising effectiveness in the use of resources and efficiency of educational administration 4. Relation between planning for the university and for education outside the university ; and the relation between educational planning and national planning in other sectors
STRUCTURE	1. Integration and differentiation of post-secondary education with a view to co-ordinating higher vocational training with the corresponding sectors of university education 2. Formulation of more explicit long-term educational goals with parallel system of educational planning 3. Development of participant education at the secondary level in which out-of-school education for young people and part-time vocational training are fused, in conjunction with general education 4. Establishment of an educational planning and innovation structure for all sectors of education, other than universities, within which medium- and long-term policies can be drawn up
OTHER	1. Development of scientific evaluation techniques for the study of goals, curriculum development and the processes of learning and teaching 2. Establishment of means of technical analysis of long-term educational trends as a part of the wider question of educational planning

NORWAY

POLICY	1. In sparsely populated areas, basic education at the primary level to be strengthened, and specialised teachers placed in lower secondary schools 2. Lack of resources - a major bottleneck in the development of the educational system
STRUCTURE	1. Expansion and reorganisation of secondary education through a system of comprehensive, general, and vocational schools 2. Development of special education for handicapped children 3. Expansion and major re-structuring of the post-secondary level : more flexible structures ; structure and length of studies ; improved university government 4. Development of a programme of recurrent education taking into consideration its organisation and financing 5. Study on the possibility for substitution between traditional education for young people and post-work education 6. Establishment of district colleges parallel to universities
OTHER	1. Study of the means of measuring the effectiveness of education

Table VIII.1

INVENTORY OF EDUCATIONAL ISSUES IN MEMBER COUNTRIES (Contd.)

PORTUGAL

POLICY	1. Better use of existing personnel and improvement in training, conditions of work and remuneration 2. Difficulty in obtaining sufficient finances for the development of education
STRUCTURE	1. Reform of secondary school structures taking into account the prolonged period of compulsory education, the future characteristics of Portuguese society and the needs of the labour market 2. Development of polytechnic education to replace middle-level technical education to provide more qualified manpower 3. Reform of the central and regional structures of the ministry of Education 4. Development of a national plan for recurrent and permanent education 5. Establishment of a central and regional structure for preparing, stimulating, co-ordinating and carrying out studies and experimentation in new methods and programmes of education
OTHER	1. Analysis of national and foreign experiences and problems in long-term planning, formulation of educational objectives and the means to achieve them 2. Establishment of a dynamic educational planning system with flexible middle- and long-term objectives and the integration of this system into national plans for development 3. Revision of national accounts with an analysis of educational financing for the purpose of defining and standardising the collection and analysis of such information and the co-ordination of public and private spending in education

SPAIN

POLICY	1. Need for economic resources to finance the new General Education Law 2. Systems for determining the cost of education 3. Training of highly qualified scientists and technicians 4. Level of salaries of teachers and a general system of salaries in relation to the labour market 5. Systems for the construction and equipping of school buildings
STRUCTURE	1. Mixed systems of education and work for students in higher education 2. Fundamental reform of the structures of universities to develop research as well as the preparation not only of scientists but professionals and teachers
OTHER	1. Establishment of indicators to evaluate the "return" to education 2. Educational planning in the context of economic and social planning 3. Programmes to organise and initiate new research in education

Table VIII.1

INVENTORY OF EDUCATIONAL ISSUES IN MEMBER COUNTRIES (Contd.)

SWEDEN

POLICY	1. Cost-benefit studies on some branches of post-secondary education 2. Review of system of government educational appropriations, one objective being to allow greater freedom in resource allocation at the local level 3. Estimates of the quantitative individual demand for education and the subsequent output of the educational system 4. Evaluation of measures taken and achievements in relation to educational goals
STRUCTURE	1. Development of adult education and training 2. Development of flexible educational structures where relations between education and the labour market can be built in (in contrast to manpower forecasts) 3. Development of new vertical and horizontal structures of secondary and post-secondary education as a mechanism for a new relationship between education and the labour market by introducing periods of work into periods of study and recurrent education
OTHER	1. Development of uncomplicated methods of evaluating, generalising and disseminating the results of experiments in education 2. Means of evaluating the educational system to provide continuous information about educational outcomes to educational planners 3. Factors influencing choices of education within the upper secondary and post-secondary levels

SWITZERLAND

POLICY	1. Development of a long-term education policy for the cantons and the nation as well as the technical means of analysing the long-term trends in education 2. Lack of specialists and means to carry out appropriate studies for regional or national educational planning 3. Continuing expansion of the universities
STRUCTURE	1. Resolution of the problem of centralisation, co-operation and co-ordination of the expansion and development of education in view of the federal structure of Switzerland 2. Increase the level of "scolarisation" and diversification at both secondary and university levels 3. Establish closer relationship between general secondary education and technical training 4. Develop a plan for continuing or permanent education 5. Lack of political body with authority to take the policy/planning decisions necessary for the development of education 6. The reform of teacher training as the key problem in educational reform
OTHER	1. Lack of comparable inter-cantonal statistics of education

Table VIII.1

INVENTORY OF EDUCATIONAL ISSUES IN MEMBER COUNTRIES (Contd.)

TURKEY

POLICY	1. Study of the costs of higher education as the basis of allocation of resources in investment and current expenditure 2. Increase in the capacity of public universities blocked by lack of funds 3. Non-fulfilment of enrolment objectives in the fields of agriculture and medicine 4. Priority to be given to technical training and professional education to meet the needs of the Turkish economy 5. Improve the quality of instruction by enlarging teacher training schools and raising the economic and social status of teachers
STRUCTURE	1. Development of literacy programmes 2. Expansion and extension of regional schools to the secondary level 3. Reform of secondary education by breaking down the rigid distinctions between disciplines to respond to the diverse needs of the students and society 4. Reorganisation of the educational system to ensure complete enrolment at the primary level by 1972
OTHER	1. Research in education is insufficiently developed for long-term planning

UNITED KINGDOM

POLICY	1. Continued and fuller development of positive aid programme to socially deprived areas and to areas with Commonwealth immigrant settlements 2. Need for more of most able scientists, engineers and technologists to take up employment in industry rather than continue in university research 3. Examination of alternative methods of financing education
STRUCTURE	1. Development of alternative methods of providing education for the 16-19 age group 2. Obstacle of the external examination system 3. Increase the use of the Industrial Training Act to provide opportunities for workers to receive continuing training and further education
OTHER	1. Examination of the quantitative implications of long-term educational developments in terms of money, manpower and other resources to provide fuller justification for increasing the allocation of these resources to education 2. Establishment of planning and management techniques at a national level as a framework for planning

Table VIII.1

INVENTORY OF EDUCATIONAL ISSUES IN MEMBER COUNTRIES (Contd.)

UNITED STATES

POLICY	1. Development of a co-ordinated strategy and the identification of priorities upon which educational research and development should be focused 2. Low level of support for research and development in education relative to total educational expenditure 3. Ever-increasing access of the socio-economically disadvantaged to educational opportunities required for full participation in American life 4. Re-examination of traditional financing and new proposals and approaches for financing the educational sector in view of the increasing difficulties in this sector due to rising costs 5. Examination of the implications of : shift from quantity to quality of instruction ; future financial needs ; disparities among districts and states ; sources of funds ; possible efficiencies in non-public schools
STRUCTURE	1. Federal government's role in education and its development 2. Reform of the university structures to cope with problems of mass higher education 3. Development of a programme of recurrent or career education as a broader concept than re-training 4. Establishment of a national central educational agency concerned with a national policy for the development of education
OTHER	1. Reliable and valid data, standardised to allow development of social indicators and the rational allocation of resources to education

YUGOSLAVIA

POLICY	1. Changes in the sources of financing of further educational development 2. Introduction of measures designed to cut down prolongation of education, to reduce dropout, to rationalise school building, etc. for the purpose of improving the effective use of resources in education 3. Secondary school education made available to all children of compulsory school age before 1985 4. Development of better conditions for adult education as a specific element in social programmes and methods 5. Development of a methodology of determining the patterns of skills for different occupations and ensuring the appropriate pattern of skills needed by the economy and society
STRUCTURE	1. Reform of teacher training system to provide the teaching staff with up-to-date training 2. Reform of higher education through radical changes in curriculum and the internal organisation ; rationalisation of higher education institutions ; integration of higher education into society ; continuous improvement of curricula and teaching 3. The relationship between scientific and technical revolution and education under the constitutional conditions of a self-governing socialist society 4. Need for formal structure for the proper planning of educational development within the framework of collective labour, and the creation of special groups and teams of professional and scientific workers for the development of innovation and educational technology

(Dr. V. Brijatoff of SERVO). It was considered as a pilot exercise in order to reserve judgement on the validity and usefulness of the content analysis technique. After making an initial review of the Growth Enquiry replies furnished to them, the investigators were asked to specify the method they would use. As a result, the investigators provided us with a basic "grid" into which the results of the content analysis were to be incorporated. Specific suggestions emerged from discussions with regard to the subject and content categories of the proposed analysis. It was agreed to select five replies to be subjected to the content analysis. These replies were from the following countries: United States, United Kingdom, the Netherlands, Norway and Germany.

Before describing the trial effort, it would be useful to give a brief description of what content analysis is. The definition frequently quoted is that given by Berelson: "Content analysis is a research technique for the objective, systematic and quantitative description of the *manifest content* of communication"(1). According to this definition, content analysis is a technique for the statistical description and analysis, as distinct from casual or face value description, of the content of a communication. (The exercise carried out in the previous section of this chapter is of the latter kind.) The technique involves attaching numerical frequencies to analytic categories. The units of measurement may be words, sentences, themes, characters, items, space and time measures, etc. The author quoted above has identified at least seventeen different uses of the technique of content analysis and has illustrated these by examples. For example, to disclose international variations in the content of communications of newspapers or radio broadcasts, one may try to determine what news of common interest or relevance is carried on the media and how it is treated. Despite the growing use of the technique, it is by no means free of controversy.

Merely to illustrate the possible use of the technique of content analysis for examining priorities, we have furnished a set of examples drawn from the work sheets of the experiment described above. The tabulations are preliminary and too sketchy even to indicate the lines of analysis for our purpose.

The application of content analysis to the replies of the Growth Enquiry raises a number of serious questions. First, the question arises as to whether the replies to the enquiry are a

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1) Bernard Berelson "Content Analysis" in Gardner, Lindzey, ed. *Handbook of Social Psychology*, Addison-Wesley, Cambridge, Mass., 1954, p. 489.

Table VIII.2

TABULATION OF SELECTED RESULTS OF CONTENT ANALYSIS OF COUNTRY REPLIES TO THE "GROWTH ENQUIRY" (early 1970)

UNITED STATES

	Source or Origin	Nature of Statement	Content	Importance in Text
"Compulsory" education	Communication	Analysis	Raising of the compulsory school-leaving age	3 lines
	Office of Economic Opportunity	"Head Start" Program	Extension of the pre-primary education	6 lines
	Government	Measures	Extension of post-secondary training	4 lines
Education of the physically and socially disadvantaged	Communication	Analysis of expectations	National norms on the integration of minority groups	2 lines
	Communication	"Thrust"	Access of certain target populations to educational opportunities. Improvement of disadvantaged youngsters. Education of the handicapped. Increase of the disadvantaged young people in higher education.	12 lines
	Secretary of Health, Education and Welfare Department	Testimony before House Appropriations Committee	First priority: education system should be more accessible to the poor and the disadvantaged	5 lines
	Commissioner Allen	Statement	Elimination of failure in the education of the disadvantaged	4 lines
	Communication	Definition of policy	Increase in the number of students from low-income families in higher education	4 lines
Permanent education	President Nixon	Proposal before Congress	Development of professional education	3 lines
Innovation	Communication	Analysis of innovation		2 lines
	Communication	Analysis of resistance to change	Lack of information on innovation	15 lines

KEY

Source or origin:	The source of the statement quoted in the country reply, which may be attributed to an individual or agency. If no source is quoted, the term communication is used, meaning that the statement is not known to originate from a source other than the author of the reply.
Nature of statement:	Indicates the context in which the statement was made; e.g. as an official statement of policy, as a result of analysis, etc.
Content:	A brief description of the issue discussed.
Importance in text:	Length of the statement in number of lines.

Table VIII.7(Cont.)

TABULATION OF SELECTED RESULTS OF CONTENT ANALYSIS OF COUNTRY REPLIES TO THE "GROWTH ENQUIRY" (early 1970)

FEDERAL REPUBLIC OF GERMANY

	Source or Origin	Nature of Statement	Content	Importance in Text
"Compulsory" education	Federal Government	Statement	Introduction of a tenth year of compulsory education. As high a ratio as possible in education to 10 years. Improve equality of education.	7 lines
Education of the physically and socially disadvantaged	Federal Government	Statement	To prevent restrictions to university entrance. Use of modern instructional techniques and correspondence courses.	13 lines
	Lander of the Federal Republic	Objectives	Allow the individual to reach the highest level of his potential. Facilities geared to individual ability.	17 lines
	Federal Government	Changes in educational goals.	Reform of structure of the educational system to equalise opportunities	16 lines
	Responsible government and democratic parties	Projects	Utilisation of pre-primary education to improve equality of opportunity	4 lines
Permanent Education	Federal Government	Objectives described in governmental report	Further education of university graduates. Financial staffing and organisational difficulties	11 lines
	Länder Ministers	Project	Adult education	1 line
Innovation	Länder of the Federal Republic	Objectives	Creation of new establishments for further education	4 lines
	Communication	Description of measures taken	Better use of classroom and teaching materials. Assistance to teachers.	12 lines
	Communication	Description of planning agencies	To utilise information. To rationalise the construction of schools	16 lines
	Länder ministers of education	Discussions	Training of teachers jointly on school levels	26 lines
	Länder ministers of education	New Measures	Creation of technical secondary schools. Experiments on all day schools	4 lines
	Länder ministers of education and Federal government	Discussion	Setting up a central registration office for educational research projects .	4 lines

KEY

Source or origin:	The source of the statement quoted in the country reply, which may be attributed to an individual or agency. If no source is quoted, the term communication is used, meaning that the statement is not known to originate from a source other than the author of the reply.
Nature of statement:	Indicates the context in which the statement was made: e.g. as an official statement of policy, as a result of analysis, etc.
Content:	A brief description of the issue discussed.
Importance in text:	Length of the statement in number of lines.

Table VIII.2(Cont.)

TABULATION OF SELECTED RESULTS OF CONTENT ANALYSIS OF COUNTRY REPLIES TO THE "GROWTH ENQUIRY" (early 1970)

THE NETHERLANDS

	Source or Origin	Nature of Statement	Content	Importance in Text
"Compulsory" education	Ministry and State Secretary for Education and Science	Priority Memorandum	Assure the education of every child	3 lines
	Conference of European Ministers of Education	Resolution	Education must achieve true equality	7 lines
	Ministry of Education	Studies and experiments	Democratisation of education	1 line
	Communication	Analysis	Need for nursery education	3 lines
	Foundation for research on education	Studies	Democratisation and parents' information	8 lines
	Government	New Compulsory Education Act of 1968	Compulsory education extended from 8 to 9 years	5 lines
Education of the physically and socially disadvantaged	Communication	Analysis of national policy	Measures to improve participation of socially disadvantaged groups in primary education	5 lines
Permanent Education	Ministry	Studies	The concept of "permanent" education	1 line
	Lievegoed Commission	Recommendations	Implementation of "participant" education	36 lines
	Ministries of Education, Cultural Affairs and Economy	Creation of an inter-departmental working party		18 lines
	Foundation for research on education	Studies	Out-of-school education, especially for young women	3 lines
Innovation	Report "Educational Policy and Planning"	List of fundamental aims of Dutch education	To promote research activities and develop innovations	6 lines
	Communication	Analysis	New teaching methods in nursery school	4 lines
	Academic Council	Research	Changes in university structures and curricula	8 lines
	Government	Sponsorship of seminar	Management of innovation in education	4 lines
	Communication	Analysis	Obstacles to innovation and measures to improve the situation	30 lines

Table VIII.2(Cont.)

TABULATION OF SELECTED RESULTS OF CONTENT ANALYSIS OF COUNTRY REPLIES TO THE "GROWTH ENQUIRY" (early 1970)

NORWAY

	Source or Origin	Nature of Statement	Content	Importance of Text
"Compulsory" Education	Government	Four-year programme	Necessity of compulsory education in time (9 years) and in space (all communities)	11 lines
	Parliament	Confirmation in 1969 of the policy of compulsory education	Nine year compulsory schooling for the whole of Norway	
Education of the physically and socially disadvantaged	Government	Four-year programme	Adaptation of education to physically handicapped children	8 lines
	Government	Perspective analysis	Education for all people	1 line
	Government	Financing	Increased subsidies to poor and distant communities	9 lines
	Government	Financing	Setting up an educational system giving equal conditions to all people	8 lines
	Board of School Experiments and Innovation	Experimental basis of new forms of education	Research on the organisation of studies and admission conditions in high schools	12 lines
Permanent Education	Government	Perspective analysis	Development of a system of recurrent education	4 lines
	Royal Commission	Programme	Post-work education	4 lines
	Royal Commission	Reform	Post-work education	4 lines
	Communication	Proposal	Financing of post-work education	3 lines
	Communication	Proposal	Rapid expansion of the system of recurrent education	4 lines
Innovation	Government	Potential decision	Experimental district colleges parallel to universities - new universities	4 lines
	Communication	List of measures to promote research	Assistance to teachers, Creation of regional innovation centres	26 lines

Table VIII.2(Cont.)

TABULATION OF SELECTED RESULTS OF CONTENT ANALYSIS OF COUNTRY REPLIES TO THE "GROWTH ENQUIRY" (early 1970)

UNITED KINGDOM

	Source or Origin	Nature of Statement	Content	Importance in Text
"Compulsory" education	Communication	Analysis	Raising of the compulsory school leaving age	7 lines
	Government	Education Act	Development of educational policy	25 lines
Education of the physically and socially disadvantaged	Government	Education Act	Help for deprived children	5 lines
	Government	Urban Aid Programme	Help for socially deprived urban areas	16 lines
Permanent Education	Government	Teaching of Adults	Courses by radio and television	15 lines
	Government	Refresher Education		27 lines
Innovation	Communication	Analysis	Introduction of new practices	14 lines

valid sample of all the communications available on educational policies and issues of the countries in question. Secondly, differences in the content of replies may reflect differences in respondent personalities and motives and not differences in country policies and issues. Thirdly, to what extent is the content analysis of the communication, in the case of the replies to the Growth Enquiry, biased by the structured nature of the questionnaire and the closed form of the questions asked?

All these three questions raise problems concerning the validity of the content analysis carried out by the investigators. As regards the first problem, it is necessary to check the results of the content analysis of the replies with an examination of other communications both within the organisation and outside. Such a check with a larger sample of communications is necessary before the results can be validated. As regards the second point, one can counter-argue that the interpretations of motives and personalities of those communicating are always difficult. The analysis of content categories does not take into consideration the presumed interests and intentions of the communicators. It is a problem of interpretation and the specific uses to which the results of content analysis will be put. At best, we can draw some inferences without subjecting them to any scientific tests. As regards the third, we feel that this has been a genuine drawback for the analysis since the questionnaire was more structured than would be desirable. Nevertheless, we can say *ex-post* that the questions have not proved to be that closed. The actual replies of the countries varied very much among themselves, and in most cases the actual answers do not reflect the bias introduced by the question.

Nevertheless, we may suggest a few interesting possibilities for use of the results of content analysis, when and if it is carried out for the purposes postulated here. The results of content analysis on the statements of national authorities regarding educational issues in their respective countries can be used as raw material for further investigation to test the relationship of these communications to the purposes and results of the model-building effort in education. This means that we propose to match or compare the content source with the non-content source. In our case, the latter would be the summary statement on the uses and purposes of each of the mathematical models of education. One could show to what extent a breakdown of models by their specific purposes coincides with the elements drawn from the content analysis of the communications received from national educational authorities.

Another possible use of the results of content analysis could be to compare one body of content with another, using tabulations provided by the content analysis. This could be done by addressing oneself to one country communication at a time. For example, by showing the relatively larger emphasis placed in the communication received from the United States on assistance to the disadvantaged groups versus the smaller amount of emphasis placed in the same communication on the problem of permanent education. This, then, could be compared with a similar investigation as to the relative emphasis of these two areas in the communication, say, from the Netherlands. The upshot of this may be the ordering of priorities in one country versus the ordering of priorities in another country. In other words, ordinal measures of priorities could be developed as opposed to cardinal measures in terms of weighting the target variables.

Finally, one could investigate for individual countries the nature and content of the replies by studying phenomena that could be extracted through the content analysis. As was suggested by the investigators, one may compare the importance in the text of a certain subject with the results achieved as reflected in the communication. Alternatively, it may be possible to compare the substance of the communication with the sources or the origin, on the one hand, and the results identified, on the other. A large number of possibilities exist for obtaining insights from the results of content analysis of communications such as those mentioned here, and comparing these results either among themselves or with a non-content source such as the mathematical models of the education sector emerging from the countries in question. From this, the use of content analysis to determine priorities in the education sector is still an open question. It was not possible to pursue the subject any further than providing illustrative tabulations.

Chapter IX

PURPOSE OF MODELS

This penultimate chapter is divided into three sections. The first section, provocatively called "Why Models?", presents the possible purposes of model-building efforts arising from varying motivations of the authors - as well as the varying motivations of the users - of the models. The second section of the chapter reverts to the explicit purposes of the models as stated by the authors, and they have been listed merely by country. The third section of the chapter attempts to match the various country-specific issues inventoried in the previous chapter with the listing of the specific purposes of the models in each of the countries in question which appear in the section.

1. WHY MODELS?

It would be rather simplistic to assume that the ultimate purposes to which a model-building effort may be put can be explicitly stated at the outset by the authors themselves. Consciously or unconsciously, the model-building effort may be directed towards a number of purposes which can be of an extra-analytical nature. Thus, we can ask the hypothetical question: "What are the possible purposes to which model-building effort could be directed?" Any identification of these purposes will have to be of an *a priori* nature, since empirical evidence will be hard to come by and would require a special effort in the understanding of human motivations. Even so, a hypothetical statement of possible purposes could serve as a clarifying background to understand the nature of the effort, particularly in terms of its usefulness and relevance to the issues involved. We begin by listing below 15 possible purposes (or uses) of models, divided into three categories.

Models bearing on policy

1. Models as decision-making tools
2. Models to solve specific problems
3. Models for planning and control
4. Models to reduce arbitrariness
5. Models for conflict resolution
6. Models for discussion of alternatives

Models having a bearing on analysis

7. Consistency-checking models
8. Models as information filters
9. Models to approximate (and simplify) reality
10. Models as idealised systems
11. Models as "mirrors" and "mock-ups"
12. Models for gaining further insights

Models having special purposes

13. Models as ideological weapons
14. Models as scholarship
15. Models as red herrings

Models used for decision-making and problem-solving purposes (1 and 2) can be illustrated from the vast experience in the field of operations research. In most cases, the explicitly stated purpose of the models enables them to be classified as serving these purposes. Models for planning and control (3) are, by their nature, analogous to those developed and used in systems engineering. Despite the hopes of model-builders to use these control and planning techniques for attaining desired objectives within the social field, the record so far does not appear to be very satisfactory. The concept of "citizen feedback", a metaphoric use of a systems analysis tool that is currently used in advocating social and political participation arrangements, is claimed to provide interesting insights into the problems of good government covering both educational and other social sectors.

There are a number of ways of reducing arbitrariness in decisions and resolving conflicts (4 and 5). Principles of scientific validation, as part of the deductive and inductive logic underlying mathematical models, have offered us the possibility of introducing this special rationality. Insofar as mathematical models can provide consistent and rational solutions to problems, they can be used against arbitrariness of, and conflict among, decisions. Finally, the purpose of model-building effort could be to elaborate a number of options on which the policy-maker may exercise his choice (6). Information on available options and the consequence of choices among these options can serve important policy purposes.

The second group of possible purposes is related to the analysis of the phenomena under study. Consistency-checking models (7), such as national income accounts or demographic accounts, are useful analytic tools. But in order to obtain further insights it is also possible to construct models for this purpose (12). Insights may also be obtained by the use of models as approximations or simplifications of reality (9), and this is often the case. The so-called realistic models are often claimed to reflect reality and are merely mirrors or mock-ups (11). Sometimes models represent idealised systems of reality (10), such as Professor Ackoff's description of the "idealised university". Such models presumably are useful as benchmarks with which realistic situations may be compared. Because of the vastness of information concerning any complex phenomena, models may be constructed to serve as information filters (8) which will permit the extraction of relevant information for analysis.

Finally, there are a number of special purposes of models that neither serve policy purposes nor analytic purposes. But, whether to display scholarships (14) or to be used as ideological weapons (13), such models serve important purposes as well. Sometimes these might even be a deliberate intent to sidetrack the argument from the basic issue by using a mathematical model as a red herring (15).

The purposes of the mathematical models of the education sector that have been explicitly stated by the authors fall into either of the first two categories, namely policy and analytical purposes. This does not preclude the possibility of their use for purposes other than those explicitly stated by the authors. As has been stated before, it will be difficult to be concerned with this matter here without investigating the motivations underlying the effort of model construction and its use.

In the following section we simply list by country the explicitly stated purposes of the model-building efforts. In the subsequent section we will pick out those models whose purposes match the education issues extracted from the Growth Enquiry replies listed in the previous chapter.

Table IX.1

LIST OF EXPLICIT PURPOSES OF THE MODELS SURVEYED

Country	Number	Purpose
AUSTRIA	1	To describe the educational system as it now exists with a view to later developing a forecasting model.
	2	To investigate the possibility of representing the educational system as a self-adaptive process, adaptive to continuous manpower projections for short-, medium- and long-term forecasts.
BELGIUM	1	To obtain forecasts of student enrolments by university and faculty, in order to provide a basis for government planning.
	2	Suppose that the students currently attending technical high schools were to attend a given number of new industrial high schools. Where should these schools be located from among a choice of possible locations, including existing schools ? The optimal solution to be found is that which minimises the transport costs for all students attending the schools.
	3	To analyse past structures of qualifications by industry and to forecast the likely future demand for personnel of different qualifications by different industries.
	4	To forecast the future stocks and flows of individuals with various university diplomas in order to compare with estimated future demands for these diplomas.
	5	Given a demand for various types of graduates of post-secondary education, how many students should be enrolled in order to meet this demand ?
	6	To compute the resource requirements of planned university facilities in both physical and monetary terms. To simulate the effects on the resource requirements of alternative teaching programmes specified in terms of the student time-tables. The aim is to have one general model which will be applicable to specific institutions.
	7	To determine the influence of changes in new university admissions on future student stocks. The model is applied and tested using data from the University of Louvain.
CANADA	1	To provide accurate, short-term estimates of future school enrolments for the information of provincial education authorities and any national services.
	2	To provide forecasts of school and university enrolment to 1975-76 for the Economic Council of Canada, partly as a pilot study for doing regular medium- and long-term forecasts on a national basis, and partly as the educational component of a larger econometric model of the Canadian economy. (See Model 8)
	3	(a) To estimate the demand for places in the secondary educational system and to discover factors which might increase the efficiency of the system, i.e. reduce drop-outs and repeaters. (b) To estimate the demand for university education by socio-economic background and to calculate the effect of various policy variables on equality of educational opportunity.
	4	To determine provincial grants to Quebec Universities and provide standards for determination of academic salaries.
	5	To develop a model programme-budgeting and accounting system, both for short-term planning and long-term investment and location decisions for a county school system. Ontario school boards have recently been consolidated and re-organised along county lines, and this is designed as a pilot model to help them to re-organise more rationally.
	6	To reduce the cost of bussing students to schools in revised county school district systems. Eventually will also be used to determine optimal location of schools and consolidation of special school facilities.

Table IX.1

LIST OF EXPLICIT PURPOSES OF THE MODELS SURVEYED (Contd.)

Country	Number	Purpose
CANADA (Contd.)	7	To devise standardised formulae for provincial grants for operating and for capital purposes to 14 Ontario universities which will give adequate support, provide supplemental assistance to "emerging" universities (less than 1800-2700 students) allowing autonomy for management, a firm base for long-term planning and predictions of income.
	8	To determine provincial grants to local school districts in such a way as to provide minimum adequate educational facilities for all and equalise the financial burden among districts. To develop an extensive data system for the school financial systems, teacners, and pupils to aid in better planning.
	9	To calculate educational stocks as an input to the economic system. To relate educational attainment to productivity. To attempt to calculate production functions using educational stocks as an input.
	10	To provide estimates of the future stocks of manpower in the medium- and long-term by age, sex, level of education and training, by province, in order to contribute towards the development of policies for investment in human resources, their employment and utilisation.
	11	To provide estimates of the medium-term future manpower requirements arising from the growth of the Canadian economy in order to contribute towards the development of consistent policies for immigration, education and training, employment and career guidance.
	12	To develop information, planning and budgeting systems for the better management of universities, colleges and other units of higher education. Uses simulation techniques to provide information about the costs, benefits, and other consequences of alternative possible decisions.
DENMARK	1	To establish quantitative relationships between the total number of students admitted per year in a teacher training institution and the average class size when different numbers of choices of classes are offered to students, and a maximum class size is imposed.
FRANCE	1	To explain why enrolment ratios vary between regions (départements) using personal characteristics of students and economic characteristics of the départements.
	2	To trace the movement of a cohort of pupils from primary school through lower secondary school and into upper secondary school (from 6ème to 2ème) from 1962-1967. To relate the rate and direction of progression to various demographic and sociological variables.
	3	To determine the location of secondary school facilities which will be distributed throughout the entire territory of France in such a way that all students can find, at a convenient distance from their homes, a choice of programmes compatible with their aptitudes and with the needs of the economy.
	4	To determine optimal resource allocation between the economy and the educational system. Optimal is defined in terms of providing the best mix of trained manpower to the economy, given certain goals for economic growth.
	5	To forecast the requirements of the economic system for qualified manpower during the period of the VIth Plan (1970-1975) and to calculate the implications of these for the provision of educational facilities. To forecast independently the social demand for education and the possibilities for provision of facilities. To confront these two in order to establish a plan for the educational sector and thus to optimise the allocation of resources between the economic and educational systems. To investigate in greater depth the relationship between the occupational and educational composition of an industry's labour force and its productivity.
	6	To calculate the distribution of the labour force by the number of years of study in order to estimate the composition and the total stock of education embodied in the French labour force in various years.

Table IX.1

LIST OF EXPLICIT PURPOSES OF THE MODELS SURVEYED (Contd.)

Country	Number	Purpose
FRANCE (Contd.)	7	Working from the Fifth Plan projections of total employment by industry, the model projects the occupational compositions required to obtain productivity and growth objectives. These are then converted into needs for graduates of the educational system by level and type. These projections serve as a guide to the development of education during the Plan period 1965-1970. Longer-term projections to 1978 were also made.
	8	To provide information for, and develop an analysis of student flows and budgetary expenditures within the Grenoble Faculty of Sciences. To make decisions on how to allocate expenditures (other than teachers' salaries) and how to direct students. To evaluate the value of various academic programmes in terms of their possible career outlets.
GERMANY	1	To show the financial implications, first, of the growth of the educational system due to autonomous demographic growth and the increase in the demand for education and, secondly, of alternative political measures. These are indicated in terms of differing student/teacher ratios, class sizes, special classes, etc. The financial implications are quantified at the national level and contrasted with the growth of national income, total public expenditure and revenue.
	2	(a) To describe the quantitative expansion of the school system, (b) To show the effects of structural reforms, (c) To show the adequacy (quantitative and structural) of the educational system with respect to socio-economic needs.
	3	To project student output and student stocks.
	4	(a) To show the structure of the educational system and to show that individualised statistics giving rise to flows are necessary to find the structure. (b) To make projections for a simulation model. (c) To find qualitative cadres in the educational systems of the different Länder.
	5	(a) To find out the number of students who want to study various subjects. (b) To compare the supply with the demand for qualified manpower, and find out how both of these are increasing. (c) To investigate student dropouts, and lengths of study of both graduates and non-graduates. (d) To investigate student/teacher ratios. (e) To estimate space requirements per student. (f) To examine different success rates in different subjects.
	6	To discover if the supply of teachers will meet the (elsewhere) projected demand. To investigate the effect of structural reforms of the system on demand and supply.
	7	(a) To project the expansion of the number of students in Baden-Württemberg primary and secondary education, and to determine the distribution over different types of schools. (b) To estimate the teacher requirement for such an expansion.
	8	To avoid disequilibria in the allocation of teachers in different types of education.
	9	(a) To examine the quantitative expansion and the resulting financial needs of higher education. (b) To examine the adequacy of the system vis-à-vis socio-economic needs.

Table IX.1

LIST OF EXPLICIT PURPOSES OF THE MODELS SURVEYED (Contd.)

Country	Number	Purpose
GERMANY (Contd.)	10	To estimate the output from the full-time school system, vocational system and higher education ; at the different levels of output from these, and to link qualifications and subject thereof to employment.
	11	To determine particular values of transition and other parameters and thus the output distribution by subject, such that the total output from higher education institutions by 1981 will correspond as closely as possible to that specified as desirable in Widmaier's manpower requirements estimates.
	12	To measure the educative capacity of the Universities (how many students of each subject can be taught ?).
	13	To estimate teaching capacity of each university by subject of study, and to compare this with student demand for such subjects.
	14	To project the number of students in the University of Kiel until 1985 in order to estimate the future enrolment and graduate output. The supply of graduates will be confronted with the demand for graduates by the government, economy and society of Schlewig-Holstein.
ICELAND	1	To obtain accurate and consistent enrolment and output forecasts for primary and secondary general education.
IRELAND	1	To obtain estimates of future primary and secondary enrolments at the county level.
	2	To estimate future enrolments in the first cycle of secondary school on the basis of current primary school enrolments and current student choices of post-primary centres.
	3	To obtain consistent forecasts of student enrolments and student outputs at all levels of education.
	4	Given a set of desired educational targets (e.g. number of graduates of different types) in a future year, what are the inputs required to move the system from its present state to the desired target state in such a way that the constraints on the system are not violated and the performance of the system is optimised in terms of a preference function.
	5	To determine the implications upon costs and the demand and supply of teachers of : (a) rapid increases in enrolments (b) administrative changes in the way teachers are paid (proportion of state aid) (c) potential changes in schedules relating pupils and teachers.
	6	To establish quantitative relationships between patterns of course offerings and characteristics of an institution (e.g. size, number of teachers hours, mix of boys and girls). Further, the demand for optional courses will be measured and an attempt will be made to relate this demand to the institutional characteristics.
	7	To determine the best way to allocate departments to Colleges which are located at separate sites.
ITALY	1	After measuring the shortage of teachers in the Italian universities, the model proposes an "optimal" allocation of assistants and professors in each faculty of these universities.
	2	To determine budgetary allowances for primary and secondary school construction in order to reduce insufficiencies and regional differences. Same type of model as the preceding.
	3	To determine the demand and supply of graduates of higher education for the period 1965-1980 by type of qualification and the number of degree-holders in the labour force by branch of economic activity for the same period.

Table IX.1

LIST OF EXPLICIT PURPOSES OF THE MODELS SURVEYED (Contd.)

Country	Number	Purpose
JAPAN	1	To forecast the number of new entrants to upper secondary schools by type of course (general or vocational and type of vocational) and geographic region. The number of applicants for entry and the number of entrants is made a function of per capita prefectural income, the occupational structure of the population and the proportion of upper secondary school graduates in the labour force.
	2	To forecast the number of students and teachers in Osaka Prefecture.
	3	To analyse regional differences in terms of various aspects including the provision of education, the private stock of educational capital, and central and local government investment in the living environment.
	4	To investigate the hypotheses that there is a certain regularity in the relationship between the number of students in higher education (per 10,000 inhabitants) and various indices of economic activity such as per capita GNP or the proportion of the labour force in secondary or tertiary industry.
	5	To forecast the supply and demand for graduates from each level of education in order to provide the basis for the formulation of the manpower plan.
	6	To estimate student flows from student stocks and to estimate the supply of graduates by field of study to each industry.
	7	To forecast the demand for skilled and semi-skilled workers to be trained in vocational training centres as part of an overall national plan for manpower and the Vocational Training Act which has not yet been passed.
	8	The purpose of the theoretical model is to determine the optimal amount of education for each individual by maximising the discounted sum of his expected lifetime income stream and his lifetime utility index. Factors such as the availability and cost of educational facilities and the student's characteristics are taken into account. The model also attempts to determine the factors affecting the social demand for education. The practical model attempts to explain the number of applicants for admission to higher education on the basis of the results of the theoretical analysis.
NETHERLANDS	1	(a) To provide estimates of future enrolments in education. (b) To estimate the outputs of the educational system by type of qualification. (c) To form a basis for estimating total expenditure by government. (d) To provide a basis for ad-hoc advice to other interested organisations (including government ministries, committees and the public).
	2	Same as above. In addition, the model provides a link with the overall economic planning model of the Centraal Planbureau.
	3	To obtain a broad view of likely long-term developments of the educational system in terms of students, number of teachers, capital and current expenditures and the proportion of national income which will be required to support education in the long term.
	4	To estimate the future supply of individuals with specific professional specialisations in order to compare with expected demands for these specialisations with a view towards identifying possible shortages or surpluses.
	5	To use the results of the first year examinations (propédeutique) to examine the manner in which examiners' independent decisions are inter-related.
	6	To specify in descriptive terms a theory of the factors determining numerical yield for all levels of diploma within an academic field of study.

Table IX.1

LIST OF EXPLICIT PURPOSES OF THE MODELS SURVEYED (Contd.)

Country	Number	Purpose
NORWAY	1	To obtain more accurate and more consistent forecasts of how post-secondary education is likely to develop in the future under certain alternative hypotheses.
	2	To determine the future consequences in terms of enrolments, graduates and teacher needs of the current pattern of human flows in the educational system. To investigate the methodological techniques suitable for dealing with such problems.
	3	To determine an optimal allocation of entering students among different types of post-secondary education. Also, to compare this optimum with the actual entry pattern of students in the past.
	4	The purpose is to analyse the demand for teachers in terms of alternative values of parameters and variables in the model. It is an outcome of the general cost of education models and teachers are treated as a sub-system. It attempts to measure teacher inputs in terms of various types of functions of teachers in order to calculate teacher requirements.
	5	To obtain improved estimates of future costs for higher education in order to assist planning authorities to plan the expansion of universities and colleges. Especially important is to be able to foresee shortages which are likely to arise due to increased student numbers. To make explicit the implications for future educational cost which certain selected factors may have.
	6	The model attempts to provide cost estimates under various assumptions and is used in policy-making. It attempts, for example, to measure costs via teacher hour inputs taking into consideration size distribution of classes.
	7	The model attempts to provide cost estimates to upper level secondary education and is similar to the one used in measuring cost of primary education.
	8	To determine how many economically active persons with different types of education were used in 1960 per million Norwegian Kroner of : (a) output in each of 30 industries, (b) final delivery from each of 30 industries, (c) each main category of final demand such as exports, private consumption, and investment.
	9	To arrive at a quantitative configuration of the expected long-range future demand for educated labour (to 1990).
	10	The model is designed to describe the Universities of Bergen and Oslo as production systems. In so doing, faculty-by-faculty comparisons are made of costs. To investigate economies of scale, comparisons are made of the two universities.
	11	This is a generalised model for university planning and aims at improvement of the budget systems of all universities in Norway.
PORTUGAL	1	To simulate the flow of students in the different branches and levels of education within a demographic and economic context. At the same time, the model determines current expenditures and the number of teachers necessary for the functioning of the system.
SWEDEN	1	To attempt to get a picture of the actual and potential dynamics of post-secondary education in terms of inputs, stocks and outputs.

Table IX.1

LIST OF EXPLICIT PURPOSES OF THE MODELS SURVEYED (Contd.)

Country	Number	Purpose
SWITZERLAND	1	(a) To describe the evolution of the system. (b) To investigate the possible effects of the new educational system to be introduced in a few years time. (c) To investigate the effect of quantifying geographical variables in educational policy.
	2	To project both the supply and demand of teachers in secondary education for the next five years, and to examine any discrepancy between the two.
TURKEY	1	To compare and analyse costs between different institutions of higher education and between different fields within institutions. To project future cont developments in higher education. To identify policy instruments for the control of cost factors and to develop budgeting procedures.
	2	To determine the manpower needs of the economy over 15 years, and to establish the amount of education that should be produced by level and by type to meet these manpower needs. The manpower vector is determined first, and only then is the growth rate of the education system calculated to fulfill the manpower needs.
UNITED KINGDOM	1	A description and projection of educational structure and development, given : (a) expected demographic changes, (b) expected changes in transition proportions, and a description and projection of financial consequences, given : (a) and (b) above, and (c) expected changes in educational inputs.
	2	(a) To construct a detailed simulation of the British educational system for students of post-compulsory education (upper secondary and higher) and an analysis of the factors influencing these flows. A theoretical exercise with some numerical results as an illustrative by-product. (b) Using the same basic model structure, to attempt to provide quick numerical results indicating the likely size and structure of higher education in Britain up to 1982.
	3	To forecast the number of students who will be in the educational system in the next decade or two, on the basis of current economic and institutional trends. On the basis of information available in the United Kingdom manpower area, to infer how the pattern of education which is currently available needs to be changed.
	4	To know the geographical distribution of the future child population by age, in order to determine the future needs for school facilities and therefore new construction for each area.
	5	To provide a means of estimating the number of children who will stay on after the compulsory age limit in order to provide information for school facilities and construction needs.
	6	To obtain a projection of the numbers of students in the three main branches of higher education (universities, colleges of education and further education) through the 1970's. It takes off from the work done by the Robbins Committee, treats the number of students in the colleges of education as a policy variable, and attempts to show how the demand for higher education in the other two branches arises from demographic and social demand factors.
	7	To determine what factors affect the flows of students from secondary into higher education and into the labour force, and what factors affect the choice of subjects and type of institutions in higher education.
	8	To project the number of teachers available by level and type of qualification for the next 10 to 15 years in order to be compared with the teacher demand model below.

Table IX.1

LIST OF EXPLICIT PURPOSES OF THE MODELS SURVEYED (Contd.)

Country	Number	Purpose
UNITED KINGDOM (Contd.)	9	To determine whether there is a shortage of secondary teachers and whether there is a need for redistribution of teachers and to estimate the total number of teachers required by subject at the present time.
	10	To forecast number of pupils by detailed location within the Inner London Area for the purpose of determining future teacher needs (short-term) and physical facilities and construction needs (medium- and long-term). Also used by the finance branch to make short-term budgetary forecasts.
	11	To measure the equilibrium of supply and demand of teachers under certain assumptions about teacher/pupil ratios. To estimate prospective shortages and surpluses of teachers (integrated with a comprehensive education model).
	12	(a) To relate government assistance to local authorities (whose main expenditure is education) to the needs and resources of each of the local authorities by using only objective factors in such a way as to equalise the burden of the resources of each community caused by providing services of the same quality. (b) To determine amounts for new construction in such a was as to provide approximately equal school facilities across the country within the limit of total construction resources.
	13	To measure and project : (a) the number of students in further and higher education, (b) the new supply of manpower with higher education, (c) the costs of educating highly qualified manpower, (d) the total stock of highly qualified manpower. To develop these into a tool for manpower and educational planning (integrated with Model 10).
	14	To determine which levels of education are privately profitable, and which levels are socially profitable (that is, make larger or smaller contributions to national income). To demonstrate a technique of analysis so as to stimulate an interest in collecting the required data.
	15	To answer the question : Does it take fewer resources to produce a student of the same quality as time passes ? To provide a general framework for incorporating all the forces affecting the quantity and quality of inputs and outputs of the educational system.
UNITED STATES	1	To provide projections of the future development of the educational system for the planning of programmes and legislation, and for general public information.
	2	To study past and future trends in enrolment and degrees in higher education.
	3	To obtain structural estimates of the demand for higher education as a function of tuition, location of institutions, selectivity (entrance criteria), aptitude of students, income differences, draft pressure, etc.
	4	To examine the effect on various measures of student success in college of varying the student's entry characteristics, the student's college environment, and the characteristics of the college he attends. This analysis can be used : (a) to aid in the estimation of the demand for educational services and the supply of trained manpower, (b) to examine the relative efficiency of alternative educational programmes, (c) to estimate the feasibility and costs of achieving equality of educational opportunity.
	5	To present a realistic estimate of the supply and demand for college faculty from 1965 to 1985 and particularly for the supply holding a doctoral degree. To criticise the estimates which predict a serious shortage and recommend too rapid an expansion of graduate education.

Table IX.1

LIST OF EXPLICIT PURPOSES OF THE MODELS SURVEYED (Contd.)

Country	Number	Purpose
UNITED STATES (Contd.)	6	The model is designed to determine how grant-in-aid offers to college students should vary as a function of socio-economic background and aptitude. This will be done by maximising social objectives - the present value of social and private returns to higher education adjusted for redistributive effects - subject to the constraint of the private demand functions for higher education of groups of potential students defined by aptitude and socio-economic status.
	7	To provide a detailed analysis of the relation of inputs and outputs to higher education including student characteristics and teacher and physical resources.
	8	To determine the efficient allocation of subsidies to college students given alternative utility functions of the socio-economic composition of the student body.
	9	To provide an effective training vehicle for professionals and administrators involved in urban affairs on the inter-relations and complexity of decisions about urban land use, tax structure, employment, housing patterns, business activity, population and income patterns, education and other public service requirements.
	10	To develop a model which will predict the optimal development of the educational system for a developing economy given resource constraints and goals for that economy. The model is a linear programming model with several alternative objective functions.
	11	To study the following problems : (a) How does educational level affect a number of behavioural variables such as consumption, saving and risk preference ? (b) How does the educational system contribute to the formation of human capital ? (c) What have been the rates of return to the various types of quality and systems of education ?
	12	To analyse the effect of education on the level and distribution of earnings and on consumer expenditure.
	13	To provide guidelines for devising efficient methods for eliminating the shortage of qualified teachers in inner-city schools and for thereby increasing the degree of educational opportunity for ghetto students. The number of teachers, the average level of qualification of the teachers, and the average achievement level of students in a school will be determined simultaneously. School policy-makers will be able to use the equations in the model as constraints in the problem of finding the estimated least-cost combination of educational inputs which will produce a given desired average level of achievement for students in a school.
	14	To relate the productivity of undergraduate institutions, as measured by the percentage of graduates who go on to graduate school and receive doctorates, to various input variables.
YUGOSLAVIA	1	To develop a PERT model (presently on a pilot project basis) in order to implement reform measures at the secondary education level.
	2	To calculate manpower requirements in 1970 for the Yugoslav economy as a whole.

Table IX.1

LIST OF EXPLICIT PURPOSES OF THE MODELS SURVEYED (Contd.)

Country	Number	Purpose
INTERNATIONAL ORGANISATIONS	1	To design a generalised simulation model of an educational system which will calculate what will be the results of alternative policies or hypotheses. For example, to calculate what will be the effect on expenditure needs of a change in the transition coefficient from 10th to 11th grade or of an increase in the compulsory school-leaving age.
	2	To develop a tool for the use of policy-makers which simulates the future consequences and the dynamics of changes in any quantifiably defined conditions affecting the educational system. An attached manpower model simulates the effect on the stock of qualified manpower of changes in the educational system and vice versa.
	3	To demonstrate how decisions made for one of each of the three sub-models - education, manpower and the economy - affect the requirements in the other two systems. The model is a computer simulation game to be used as a training exercise and demonstration tool for national planners.

2. LIST OF EXPLICIT PURPOSES

The following listing of the purposes of models is derived from the questionnaire responses of the survey of mathematical models of the education sector. The reply of the respondent had, in several cases, to be edited by the interviewer. But, even so, several of the replies to this question are neither precise nor are they an adequate representation of the purpose orientation of the model that could be extracted after an examination of the model itself. This drawback was to some extent alleviated by a subsequent editing after a cursory review of the contents of the model. The residual problem is unlikely to be sufficiently serious to distort the overall picture that will be drawn in this chapter. These purpose statements were used, as was mentioned earlier, in describing the details of the attributes of the models in our aggregate and cross-sectional analyses in Part One and Two respectively. Here the relevant information for individual models is given, which could be further studied in its own right apart from the special use that has been made of it in this chapter.

3. POLICY PROBLEMS VS. MODEL PURPOSES

The confrontation of the explicitly stated purposes of the mathematical models of the education sector with the country-specific educational policy issues derived from the communications from the national educational authorities can provide us with interesting insights into the "practicality gap" of the model-building effort. Such information could then be utilised to find the directions in which this effort could be strengthened in order to reduce this gap.

The gap between issues and models that can be identified on the basis of the information provided here is not completely adequate or satisfactory. It is no substitute for serious efforts involving diagnostic studies on each model, and each country, in order to obtain a relatively complete picture of the problems associated with the use or the lack of use of a mathematical model for practical policy issues in the education sector of a country. Such diagnostic studies may have to be carried out by a "third party" other than the model builders or the policy-makers and administrators. An important requirement would have to be the close co-operation and understanding of the two parties with those responsible for the diagnosis.

In the absence of such detailed studies we have adopted a next-best approach as a short cut. This is to take the policy issues that are manifest from a certain set of communications from national authorities and the model purpose explicitly stated by the authors, and to match the two to discover possible interconnections. This matching was done on a country-by-country basis because most of the models have been constructed with specific reference to a given situation within the country, and also because the policy issues extracted from the communications relate to the specific country situation. Alternatively, it would have been possible to carry out a cross-country matching along the same lines as adopted for country-by-country matching. This would have provided us with information on additional potential uses of the models through a cross-country transfer of model applications to tackle specific issues of countries other than the one for which the model was initially constructed. But because of the problems already mentioned, such as the assumption of cross-country transferability of model-building technology, this would require a more careful examination of models and country situations than was possible here.

Even when we do obtain a match between a specific country-based issue and an explicitly stated purpose of a model built for that country, there is still no guarantee that the model is particularly applicable in that situation. There are a host of reasons for this, such as the erroneous specification of the relationships, the inadequacy of the basic data which may be subject to large margins of error, or perturbations and inconstancies in the parameter of the model. Some of these technical problems have been discussed in Chapter VI. This matter again calls for more detailed studies before reaching firm conclusions.

On the other hand, the problem of the practical application of the models may arise from the reluctance of those responsible for the formulation and execution of educational policies to use these techniques rather than the use of rules of thumb and judgment based on experience. A systematic discussion of this vast problem will require a host of new considerations which cannot be taken up here since our concern is the practicality gap arising from the nature of the model-building effort itself.

Tabl

POSSIBLE MATCHING BETWEEN COUNTRY-SPECIFIC ISSUES AND EXPLICITL

Country	Policy problem (issue)
AUSTRIA	Estimation and measurement of the requirements of university graduates in relation to educational planning and manpower demand.
	Establishment of a centrally-integrated information system comprisi the whole education system required for economics of education.
BELGIUM	Reforms of education structures consistent with the expansion of universities.
FRANCE	Coordination of existing action and formulation of new proposals for permanent education.
	Development of a system of permanent comparison of the methods and objectives of educational planning.
GERMANY	Reform of higher education to cope with expansion.
	Overcoming teacher shortage.
	Forecasting the qualitative and quantitative development of higher education, taking into consideration the reform of curriculum and examinations, research, organisation, trends in numbers of students and the demand for personnel, equipment and investment.
IRELAND	Increasing the supply of teachers, particularly in the applied sciences.
ITALY	Absence of a systematised means for the long-term (10-15 years) evaluation of the needs of the education sector.
JAPAN	Balancing the social demand for diversification of upper secondary education and the aspirations of the people for increased opportunity for more advanced education.
	Ceiling on the expansion in the demand for higher education.
NETHERLANDS	Future development of the educational system limited by lack of financial resources.
	Formulation of more explicit long-term goals with parallel system of educational planning.
	Establishment of means of technical analysis of long-term educational trends as a part of the wider question of educational planning.
	Development of scientific evaluation techniques for the study of goals, curriculum development and the processes of learning and teaching.

.2

ATED PURPOSES OF MODELS IN THE CORRESPONDING COUNTRIES

Model purpose
To investigate the possibility of representing the educational system as a self-adaptive process, adapting to continuous manpower projections for the short-, medium- and long-term forecasts.
To describe the educational system as it now exists with a view to later developing a forecasting model.
To obtain forecasts of student enrolments by university and faculty in order to provide a basis for government planning.
To forecast the future stocks and flows of individuals with various university diplomas in order to compare with estimated future demands for these diplomas.
To calculate the distribution of labour force by the number of years of study in order to estimate the composition and the total stock of education embodied in the French labour force in various years.
To determine optimal resource allocation between the economy and the education system. Optimal is defined in terms of providing the best mix of trained manpower to the economy, given certain goals for economic growth.
(a) To describe the quantitative expansion of the school system. (b) To show the effects of structural reforms. (c) To show the adequacy (quantitative and structural) of the education system with respect to socio-economic needs.
To discover if the supply of teachers will meet the (elsewhere) projected demand. To investigate the effect of structural reforms of the system on demand and supply.
(a) To examine the quantitative expansion and resulting financial needs of higher education. (b) To examine the adequacy of the system vis-a-vis socio-economic needs.
To determine the implications upon costs and demand and supply of teachers of : (a) rapid increases in enrolments, (b) administrative changes in the way teachers are paid, (c) proportional changes in schedules relating pupils and teachers.
To determine the supply and demand of graduates of higher education for the period 1965-1980 by type of qualifications and the number of degree-holders in the labour force by branch of economic activity for the same period.
To forecast the number of new entrants to upper secondary schools by type of course (general or vocational, and type of vocational), by geographic region, etc.
The purpose of the theoretical model is to determine the optimal amount of education of each individual by maximising the discount sum of his expected lifetime income stream and his lifetime utility index. The practical model attempts to explain the number of applicants for admission to higher education on the basis of the results of the theoretical analysis.
(a) To provide estimates of future enrolments in education. (b) To estimate outputs of the educational system by type of qualification. (c) To form a basis for estimating total expenditure by government.
In addition, the model provides a link with the overall economic planning model of the Centraal Plan Bureau.
To obtain a broad view of likely long-term developments of the educational system in terms of students, number of teachers, capital and current expenditures and the proportion of national income which will be required to support education in the long term.
The use of the results of the first year examinations (propédeutique) to examine the manner in which examiners' independent decisions are interrelated.
To specify, in descriptive terms, a theory of the factors determining numerical yield of all levels of diploma with an academic field of study.

Tabl

POSSIBLE MATCHING BETWEEN COUNTRY-SPECIFIC ISSUES AND EXPLICITLY

Country	Policy problem (issue)
NORWAY	Expansion and major re-structuring of the post-secondary education level : more flexible structures, structure and length of studies, improved university government.
	Lack of resources - a major bottleneck in the development of the education system.
PORTUGAL	Establishment of a dynamic educational planning system with flexibl middle- and long-term objectives, and the integration of this syste into national plans for development.
SWITZERLAND	Development of a long-term educational policy for the cantons and the nation, as well as the technical means of analysing the long-term trends in education.
TURKEY	Increase in the capacity of public universities blocked by lack of funds.
	Study of the costs of higher education as the basis of allocation of resources in investment and current expenditure.
UNITED KINGDOM	Examination of the quantitative implications of long-term educational developments in terms of money, manpower and other resources to provide fuller justification for increasing the allocation of these resources to education.
	Establishment of planning and management techniques at a national level as a framework for planning.
UNITED STATES	Ever increasing access of the socio-economically disadvantaged to educational opportunities required for fuller participation in American life.
	Establishment of a national central educational agency concerned with a national policy for the development of education.
YUGOSLAVIA	Development of a methodology of determining the patterns of skills of different occupations and ensuring the appropriate patterns of skills needed by the economy and society.

.2 (Contd.)

ATED PURPOSES OF MODELS IN THE CORRESPONDING COUNTRIES

	Model purpose
	To obtain more accurate and more consistent forecasts of how post-secondary education is likely to develop in the future under certain alternative hypotheses.
	To determine the optimal allocation of entering students among different types of post-secondary education. Also, to compare this optimum with actual entry patterns of students in the past.
	The model attempts to provide cost estimates under various assumptions and is used in policy-making. It attemps, for example, to measure costs, via teacher-hour inputs, taking into consideration size distribution of classes.
	To simulate the flow of students in the different branches and levels of education with a demographic and economic context. At the same time, the model determines current expenditures and the number of teachers necessary for the functioning of the system.
	(a) To describe the evolution of the system. (b) To investigate the possible effects of the new educational system to be introduced in a few years' time. (c) To investigate the effects of quantifying geographical variables in educational policy.
	To compare and analyse costs between different institutions of higher education and between different fields within institutions. To project future cost developments in higher education. To identify policy instruments for the control of cost factors and to develop budgeting procedures.
	A description and projection of educational structure and development, given (a) expected demographic changes, (b) expected changes in transition proportions ; and a description and projection of financial consequences, given (a) and (b) ; and (c) expected changes in educational inputs.
	(a) To construct a detailed simulation of the British education system for students of post-compulsory education (upper secondary and higher) and an analysis of factors influencing these flows, etc. (b) Using the same basic model structure, to attempt to provide quick numerical results indicating the likely size and structure of higher education in Britain up to 1982.
	To examine the effect on various measures of student success in college, of varying the student's entry characteristics, the student's college environment and the characteristics of the college he attends. The analyses can be used (inter alia) to estimate the feasibility and costs of achieving equality of educational opportunity.
	The model is designed to determine how grants-in-aid offers to college students should vary as a function of socio-economic background and aptitude, etc.
	To determine the efficient allocation of subsidies to college students given alternative utility functions of the socio-economic composition of the student body.
	To provide projections of the future development of the educational system for the planning of programmes and legislation, and for general public information.
	To provide guidelines for devising efficient methods for eliminating the shortage of qualified teachers in inner-city schools and for thereby increasing the degree of educational opportunity for ghetto students, etc.
	To calculate manpower requirements in 1970 for the Yugoslav economy as a whole.

Despite these caveats, we have used the matching approach as a screening device. Other things being equal, when we can find a match between a model purpose and a policy issue there is a prima facie case for the potential (if not actual) applicability of the model to that particular problem. This is, at best, a necessary condition and certainly not a sufficient condition.

From the tabulation above one can readily read off the possible match between a specific issue and the purpose of a mathematical model, both in the context of a specific country. Thus, we find, for example, that the concern of the national authorities in Norway with the lack of resources for the expansion of the education sector could, in part, be tackled with the model that has been constructed with the purpose of providing cost estimates under assumptions concerning teacher hour inputs, class sizes, etc. This is one of the examples of possible coupling (which in many cases may already exist) between the model-building effort and the policy problems of national authorities.

Chapter X

CONCLUSION

In this concluding chapter we shall simply present a brief summary of findings based on the analyses of the mathematical models of the education sector surveyed in this report. These findings are neither conclusive nor comprehensive. They reflect the judgement of the authors in the light of the survey with which they have been involved over the last two years. Next, we shall abstract the recommendations of a specially concerned group of experts on priorities for future work in the field. These experts were not governmental representatives, and their joint statement reflects their views in an individual capacity. Finally, we shall make a proposal for an effective means of cross-country information exchange through an international clearing-house facility that will continuously attempt to match existing and newly developing mathematical models and techniques with the current and foreseeable issues of educational policy.

1. SUMMARY OF FINDINGS

In the report we have presented a first aggregate look at a large number of current mathematical models of the education sector surveyed in the OECD Member countries, and have shown their distribution in terms of number of classificatory characteristics. This was followed by a cross-sectional study of individual models distinguished by their subject matter and structural features. Wherever called for, comments were made on technical procedures and problems. In only three cases was an attempt made to carry out in-depth studies of selected models. Finally, drawing upon a set of communications received from national education authorities, it was possible to calibrate the explicitly stated purposes of the models with the main issues of each country derived by a theme analysis.

Apart from a number of unorthodox procedures used to analyse the vast body of information available to us, the main body of the report comprises a straightforward cross-sectional description of the models from a number of different viewpoints. The material offered in the report is therefore difficult to summarise. There are many problems of mathematical model-building that could not be covered and the basic raw material offers considerable opportunities for further exploitation. We can, however, make some general comments in the form of broad conclusions which emerge from this report.

Throughout the report, we have referred to a number of dichotomies that have vitiated the theory and practice of mathematical model-building for the education sector. We will now restate these dichotomies in order to suggest the ways in which the future efforts could be made to alleviate some of the roadblocks standing in the way of an effective development of the art.

Structure vs. Behaviour

The general physiognomy of the very considerable model-building effort is quite clearly one in which the structuralist viewpoint prevails, as reflected in the student flow models used for forecasting. In general terms, the model-builders in education have adhered either to a structuralist viewpoint of education or a behaviouralist viewpoint. According to the structuralist viewpoint, prevalent in Western Europe largely, the educational process can be divided into a number of channels and stages and the transition of students from one to another is then examined. The factors governing the transition proportion are treated more or less outside the model. With this viewpoint education at the macro or sectoral level is regarded as an input-output process analogous to the input-output relations describing the production process of the economy as a whole. But the behavioural transition coefficients of an educational model are quite different from the technological input coefficients of an economic model. For one, the former are far less stable than the latter. We found only limited attention paid to an examination of the behaviour which governs the value of the transition coefficients. The relative lack of emphasis on models and studies which would explain the magnitude and changes of the parameters of the student-flow system is deplorable. Insofar as the transition proportions constitute the strategic parameters of the models, greater knowledge of the determinants of these parameters ought to be the first order of business. It appears that the virtue of consistency in building overall models has been realised at the cost of neglecting less glamourous, but more crucial, work on explaining the behaviour of the transition proportions, attrition rates, etc., in terms of major demographic, sociological and economic variables. Such work can be fruitfully carried out in research institutions on a continous and long-term basis.

If we examine the substantive meaning of the relationship of the stock-pile of mathematical models of the education sector, we find few of these that could be classified as behavioural. Even for a large model containing hundreds of equations, one finds that most of these may be accounting identities which are manipulated more or less mechanically. Forecasting with the aid of models, whose power is restricted to consistency-checking, often ends in tautology since all strategic variables reflecting human behaviour are considered exogenous.

The behavioural viewpoint has been adopted by two types of studies predominantly carried out in the United States. Inspired by the problem in the United States of the lack of equal educational opportunity for individuals by reasons of race, religion or national origins in public educational institutions at all levels, a large number of studies have been made to test hypotheses concerning the determinants of differences in achievement levels of students of different socio-economic groups. A second type of study has been concerned with the economic valuation of education to individuals or to society in terms of returns on investment in this sector.

The behavioural approach, as compared with the structural approach, has been of a piecemeal character, providing insight into the patterns of human reactions often at a micro level. Even if we have well-tested hypotheses concerning motivation and behaviour of individuals with regard to their educational choices, it is not self-evident that these relationships can be consistently put together into an overall model of education to be used for making policies or forecasts. Each of these two broad approaches to model-building in education - the structuralist and the behaviouralist - has certain merits, but for purposes of making policies and planning in the educational sector it can be proposed intuitively that both the approaches constitute a necessary condition, and their reconciliation would also constitute a sufficient condition. Therefore, we need "mix models" blending both these aspects to provide a relatively complete description of the complexities of education.

Micro vs. Macro Approach

Another dichotomy that characterises the model-building effort in education, as well as in many other fields, is the difference between the macro and the micro approach. The former is concerned with the study of large aggregates and the latter with the individual components of that aggregate. In economics, the study of the national economy as a whole dealing with such variables as national income, employment level and the rate of interest, belongs to the field of macro economics; whereas the study of the firm or the household belongs to the field of micro economics. Analogously, we may speak of macro educational studies concerned with variables describing the education sector as a whole or its major parts, while micro education studies would be concerned with individuals in their role as decision-makers confronting educational choices and those institutions that are concerned with the provision of educational services. Enrolment levels, private and public expenditures on education, skill qualifications generated and capital formation in the education sector are the typical macro variables. Capacity of an individual educational institution, its recruitment choices, and subject mix are some of the micro variables concerned with educational establishments. As far as the individual is concerned we are interested, for example, in his demand function which relates his personal income to his choices between pursuing education or seeking employment. These examples will suffice to show the nature of the distinction between the two approaches.

While in economics the mosaic of general equilibrium theory has attempted to fit the micro pieces, namely firms and households, with the macro pieces belonging to the study of the economy as a whole, we know of no such attempt in the field of education. A general equilibrium theory in education will have to reconcile the micro behaviour of individual investors in, and consumers of, education and individual institutions, on the one hand, with the macro behaviour of the educational system as a whole, on the other. This could then be structured into a consistent model, not very dissimilar to the general equilibrium models of economic behaviour. Without even the rudiments of such an approach, it is difficult to bridge the prevailing gap between micro models in education and the macro models.

Rate of Return vs. Manpower Planning

This third dichotomy is the traditional controversy between the manpower planners and rate-of-returners, already cited at the outset of this report. First, if one tries to determine the costs and benefits of the various types of education, it is necessary to calculate the rate of return on investment in each of these activities. Let us take the example of the profitability of investment in university education. This requires that we assume that university graduates are paid according to their marginal social product. The wage differential between the university graduate and the non-university graduate can serve as a first approximation to the social benefit derived from each such graduate under present conditions. The social cost of university education consists of earnings foregone by the university student while he is in shcool and of the cost (teachers, school facilities, etc.) per graduate produced by the university. The internal rate of return to university education can then be estimated as that rate which, over the expected productive life of the university graduate, will make the present value of the benefits equal to the costs.

The decision rule following from this approach is that investment in each branch of the educational system be carried to a point where all internal rates of return are equal. Presumably, this equality should be maintained not only among the various educational processes, but also in the economy at large. The main difficulty with this approach is that the present and future marginal social benefits from university education, or any other type of education, are not necessarily equal. The education process works in terms of long time-horizons, non-economic objectives, and structural changes in the system and related systems, which make it difficult to justify the application of static criteria in an essentially long-period dynamic situation.

A second approach is to apply the criterion of manpower requirements to determine the educational needs in the country. This is a unilateral mechanical approach for determining the demands on the educational system, as generated within the production sectors of the economy, with given technological labour-output coefficients. The coefficients are used in the computation of manpower needs for each class of manpower and for each sector of the economy. The direction of causality is to project the productive profile of the economy, which is then converted into the manpower requirements with given technology. From the manpower requirements one sets up the demands on the educational system for different qualifications and the accompanying educational strategies. No autonomous role is granted to the education system; nor is an attempt made to build up an interactive mechanism between production profiles and educational strategies. As a result, there is a danger of a lop-sided policy approach to educational planning developing through an inflexible manpower analysis.

An appropriate mix of these two approaches may well be necessary for building practical models to assist the formulation of educational policies.

Practicality Gap

The survey provides sufficient indications, though in a somewhat oblique fashion, that there is a considerable gap between the construction of formal mathematical models, on the one hand, and their use in educational decision-making and policy planning, on the other. It is difficult to seek explanations from model-builders for the reasons for this gap. One could, however, speculate that most model-builders have not given a high priority to the actual use of their own models since they have been interested in the academic and experimental value of this art, which is still in its infancy. If we are to compare model-building in education with a similar activity in economics, it is certainly safe to conclude that the experience in the former is still extremely limited. It is therefore not very surprising to find educational administrators and policymakers still somewhat cynical about mathematical models in general.

But there are, certainly, noteworthy exceptions to the general failure to use effectively the educational models. In the Netherlands, for example, a large-scale comprehensive model of the education system is currently being used for short-term forecasting in the Centraal Planning Bureau. Also, in Norway, a somewhat larger and more complex model is an essential element in the continuous decision-making process with regard to short-run budgetary allocations as well as long-run capital expenditure plans. A greater and more widespread effort in the construction and use of policy models is obviously needed. A matching of the model purposes with the specific policy issues in countries has indicated that in a number of cases there are promising opportunities for tackling concrete issues with the aid of mathematical models, if this has not already been done. A further opportunity for the cross-country transfer of mathematical models needs to be explored.

Other Issues

In a large number of models there is lack of simultaneity in the system of equations. This means that there is no feedback mechanism in such models. Each step is determined by the previous one, which in turn determines the next step. This results in an over-simplification of how the system operates and the underlying causal relationships. Furthermore, there is no consideration of the sizes of the models, and justification is rarely given on the choice of the level of aggregation. We know, however, that the larger the size of the model, the larger is the error resulting from "noise" generated by solving the system of equations. It would be desirable, therefore, to check errors involved in disaggregating the system into such great details as is done in a number of cases. The results produced by highly disaggregated models should be compared with results produced by other more aggregate and/or naive models. It may often be the case that more aggregate models have produced more acceptable results.

Finally, the consequences of greater emphasis on long-term forecasting models as against forecasting and other problems of short-run character are hard to evaluate. It is true that the education system, by its very nature, has a long-run character. Decisions in education, such as lengthening the secondary school going period, have long-run consequences. Demographic factors affecting numbers of school entrants are again long-run forces that are hardly amenable to short-term forecasting. But there are a number of decisions in government that are to be made in the short run: short-run enrolment forecasts and their consequences for budgetary allocation are probably a routine but important annual consideration of ministries of education. To strengthen decisions like these, model-builders need to pay increasing attention to the short-run forecasting problems too.

2. RECOMMENDATIONS FOR FUTURE WORK

The results of the survey were presented for review to a meeting of national experts in the field, who were asked to make recommendations as to the best way for OECD to pursue work in educational model-building. The small group of experts, chaired by Professor Claus Moser, and consisting of Professors Coleman, Fox, Malinvaud, Thonstad, von Weizsäcker and de Wolff, met on 12th and 13th June, 1969, to discuss the preliminary results of the survey. A straight-forward abstract of their recommendations follows:

> One of the factors of the model-building scene which showed up clearly in both the preliminary results of the survey and in our discussion was the gap between the construction of formal mathematical models, on the one hand, and their use in educational decision-making and planning, on the other.

There are many explanations for the poor use even of basic forecasting models. One is that administrators and policy-makers are cynical about models in general: this is a feature that may gradually disappear. More serious is the fact that even some of those who are in principle favourable feel doubtful about the usefulness of some of the present research activities in this particular field. It is of course true that academic model-builders do not always rate the actual use of their models as a major objective. At the same time we want to emphasize that this is a difficult field, and that it needs a lot of basic research which may not give a quick pay-off in terms of usability and which may thus not appeal to the policy-maker. Even so, many of the research efforts could be better geared (at least in long-term aims) to practical needs; and forecasts will need to become more successful if confidence is to grow.

We are convinced that one of the major tasks now is to bridge this gap between the builders and the users of the models. The problem is, how. We are hopeful that the survey itself will make a major contribution in pointing out to what extent models actually are or are not used, in identifying the reasons why they have often been of limited usefulness, and in suggesting ways in which the gap might be bridged. We also feel that the further work on forecasting models should have as one of its main objectives an attempt to make this particular kind of planning tool relevant to the needs of educational decision-makers and forecasters and to convince these latter that mathematical models can be of use to them.

Student parameter models, which attempt to evaluate and explain the parameters of student forecasting models, and models concerned with productivity or student attainment, which evaluate the influences of various inputs into the educational system on its output, should be further explored in the context of the survey. These are thus important auxiliaries to resource requirements models.

Resource Requirements Models

Governments are vitally interested in the problems of resource allocation in the educational system. This means decisions on the total resources to be devoted to education, and their allocation to different levels, sectors, regions, and so forth. At their simplest, one can think of resource requirements models as a straight translation of student numbers - as derived from forecasting models - into terms of staff, money, buildings. But this is only a small aspect of the field, the major interest being in how to arrive at optimal or near-optimal decisions on how to allocate resources: how to choose the "best" teacher/pupil ratios, how to arrive at good siting decisions, and so forth. This is so far a relatively undeveloped field, especially as regards the links between the outputs of the educational system and alternative resource inputs. We feel, therefore, that the survey material could help to show why "explicit", comprehensive models have not been used in planning and decision-making and to evaluate what their strengths and weaknesses are. In particular, one would like to know whether models can be built to be general and flexible enough to calculate quickly the resources needed for various alternative projections of student numbers; and, also, to what extent planning models can aid in the determination of the development of the educational system through time and indicate what decisions need to be implemented each year so as to arrive at a particular goal in some future year. Furthermore, the survey material on allocation models of the linear-programming type should be further and critically studied.

Student Attainment or output (behavioural model) is one of the most important areas for development in educational model-building and one, moreover, in which Europe (as opposed to the United States) is weak. However, since various other bodies are working in this field and the approaches will differ greatly from country to country, we do not think that it should have priority, as regards substantive research in our context.

Externally-Linked Models

We discussed the links between educational models and different kinds of economic models, notably those specifying manpower targets. We agreed that the link between these various types of models is crucial and that much work remains to be done on manpower models as such. There are many weak links in the methodology, above all that between education and occupation, and the substitution of people with different kinds of backgrounds in given jobs.

Recommendations for: Further Work on Forecasting Models

A striking feature of our discussion was the predominance of interest in student forecasting models (including those types of evaluative models which the report refers to as student parameter models, viz. models concerned with the actual estimation of transition proportions in traditional forecasting models). This concentration is not really surprising. Most countries are interested in forecasting student numbers and so are many researchers active in this field. Besides, many other types of model - e.g. the resources allocation and the externally-linked models - need student forecasts as one of their inputs. There is of course some temptation to turn away from student forecasting models, if only because they have so often gone wrong, and to concentrate on decision-type models which give the semblance of avoiding the forecasting issue. But we are agreed that because of the importance of general enrolment models to policy-makers, and because the methods used in them are still capable of great improvement, they should have priority.

Moreover, we think that attention should first be given to a post-mortem on forecasting models. It is true that most of the student forecasts in different countries have turned out to be wrong, generally underestimating demand. If so, is there any evidence in individual countries why this is so? (We know that in the United Kingdom and in the Netherlands there have already been post-mortems). Have the wrong hypotheses or theories been relied on for the forecasts, have inadequate relationships been built into them, have the data been faulty?

It is tautology to say that the main reason for wrong forecasts must lie in the estimation of parameters. We are agreed that one of the follow-ups of the survey should be to examine fully the different methods used for estimating transition proportions in forecasting models. Many theories or hypotheses are used in relation to particular parameters (e.g. Stone's "Epidemic" theory) and many empirical methods are employed (such as surveys into student preferences), including methods geared to solving the "bottleneck" problem. We feel that this accumulated experience needs to be systematised. We attach particular importance to work on the economic factors affecting transition proportions, including both market factors (such as prices and wages) and policy factors (such as scholarships); and in addition to this concentration on various kinds of structural changes in the educational system (e.g. in course structures and syllabuses), on student flows. Our impression is that many forecasting models are too inflexible, taking the structure of the system, including the content of courses, as virtually fixed.

Among the factors affecting transition proportions are policy variables of various kinds, and we agreed on the importance of identifying not only the parameters in forecasting models which were of particular policy significance, but also of assessing how sensitive they are to changes or false assumptions in the policy variables included in the model (a loose form of sensitivity analysis). It therefore seems important to accumulate evidence on what policy instruments are used in different countries for different educational aims, and on their effectiveness. This latter aim is of course a large topic in itself and is one of the very purposes of model-building. But it seemed to us that a start could be made, from the survey material and other sources, in systematising what experience there is to date.

Summary of Recommendations

The two activities recommended are:

A. Further work on the survey itself, including:

- i) Presentation of the general results of the survey;
- ii) Case-study analysis of particular models;
- iii) Further investigation and discussion of the material already collected on student forecasting models, resource requirements models, and externally-linked models;
- iv) A detailed examination of the usefulness of evaluative models in improving both student forecasting and

resource requirements models, with possible suggestions for a future research project.

B. Further work on forecasting models, and especially:

  i) A post-mortem on past models;
  ii) A study of different methods used for estimating transition proportions;
  iii) A study of policy variables.

3. A PROPOSAL

Because there is prima facie evidence that mathematical models of the education sector offer promise of providing assistance in the solution of some practical problems of educational policy, it may be useful to propose a trial exercise which could facilitate the realisation of such a hope. We know that there is a large stockpile of mathematical models of the education sector, comprising many models of different kinds built with specific reference to a situation within a given country. Initial screening of the explicitly stated purposes of models indicates that the models may have considerable relevance to the concrete situations to which they may have been addressed in the country of their origin. But there is an equally promising opportunity for application on a cross-country basis.

How can we realise the cross-country transfer of model techniques, in addition to strengthening its practical usefulness at home? A number of countries undoubtedly face policy problems amenable to the application of mathematical models but may find such techniques lacking within their own boundaries. Rather than repeat the experience of others through a costly duplication of effort, it would be more efficient to draw upon the existing technology, if it is readily available.

The basic assumption of this proposition is that models developed in one country are easily transferable to another country for possible application. This assumption would be valid for models whose problem-solving structure is of a sufficiently general nature to permit such transferability. In the case of those models where the special features of a given country are predominant in the structure of the model itself, then the problem of transferability is much more serious and would probably be unfeasible. But in those cases where an examination reveals that the models have sufficiently generalised elements, then there should be an organisational apparatus for effecting the transfers.

We need an information clearing-house on mathematical models and techniques supplemented by an issues bank for cross-country use. Information of this kind, however, will have to be continuously up-dated because of the rapid rate of obsolescence in the state-of-the-art concerning model-building, as well as the relevance of country-specific issues of policy-makers with the passage of time. A self-updating issues file and a model file, adequately cross-referenced, will need to be developed with imagination and expertise in order not to overload the system, with full and complete information from each country as well as on each mathematical model. What is required is the key items of information of both kinds that will enable a useful matching that could yield relevant information on cross-country potential for model application.

Furthermore, the information input regarding the policy issues will require the co-operation from public authorities who as major potential beneficiaries could be convinced of the utility of such an apparatus. The advantages to the model-builders of cross-country fertilisation of ideas is already well-recognised and no convincing will be required to solicit their support.

Such a facility should essentially serve the purpose of identification and not of detailed information-gathering and dissemination. It will not therefore be nesessary to accumulate centrally a vast body of information or documentation concerning every detail of the models, and the data on which these models have been based and their estimated parameters. It will be sufficient to obtain only that information which could be useful in identifying the techniques and approaches underlying the models and their applicability to specific issues of policy. The facility could have a built-in query service. This would have the advantage both of providing the facility with a means of identifying additional "centres of interest", and of offering a quid pro quo for the co-operation required.

It can be argued that there are more fundamental reasons for the failure of models to be applied in practice. Indeed, there are those who would argue that the pursuit in the development of new and better techniques offers little opportunity for success and, given the costs involved, should be abandoned. The thrust of this survey, from the viewpoint of the authors, does not bear out this contention. The magnitude and diversity of the effort is far more widespread than was foreseen prior to embarking upon the survey, which demonstrates that this activity is not confined to a small group of researchers in the field.

By using an independent source of information, we have shown that model purposes and policy issues are not as divorced from one another as had originally been thought. We have, therefore, proposed a way to monitor both the model-building effort in the education sector and its relevance to educational policy-making, in the hope that they can be made to converge more rapidly.

LES MODELES MATHEMATIQUES
DU SECTEUR ENSEIGNEMENT

SYNTHESE (1)

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(1) L'auteur de cette synthèse est Alain Morineau, Collaborateur de recherche, CEPREMAP, Paris.

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Troisième Partie

PROBLEMES ET OBJECTIFS

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I. INTRODUCTION

A mi-chemin entre l'exposé détaillé et la simple bibliographie, cette étude constitue l'analyse globale d'un large ensemble de modèles révélant, par le biais d'un système de classification, l'anatomie des recherches effectuées sur les modèles mathématiques du secteur Enseignement. On y trouvera l'occasion de confronter les idées et les techniques, en même temps que le support d'un échange souhaitable d'informations entre chercheurs. Une telle entreprise devrait, en outre, contribuer à combler le fossé qui se creuse entre les constructions raffinées de modèles, d'une part, et leur utilisation effective comme instrument préparatoire à la décision, d'autre part.

Ce travail, confié en 1968 au Comité du Personnel scientifique et technique par le Secrétariat de l'OCDE, marque une étape du programme poursuivi par l'Organisation en matière d'étude statistique et quantitative de l'enseignement. A son actif se sont inscrits en particulier des congrès d'experts centrés sur les thèmes de la planification et de la rationalisation (mars 1966, janvier 1967, avril 1968, avril 1969), une bibliographie choisie et annotée sur les Méthodes analytiques appliquées à la planification de l'enseignement (OCDE, Paris, 1969), ainsi que l'étude et la réalisation de deux modèles : l'un d'interactions entre les trois secteurs Enseignement-Main-d'oeuvre-Economie, l'autre, de simulation concernant le secteur Enseignement.

L'intérêt présenté par un tel inventaire de l'ensemble des recherches transcende d'ailleurs le seul contexte OCDE et se justifie par l'importance des modèles, à l'échelon gouvernemental, pour argumenter l'accroissement des dépenses dans ce secteur (en particulier dans l'enseignement supérieur), pour étudier et améliorer l'efficacité de ces dépenses et, du côté théorique, pour faire le point des controverses sur le moyen d'inclure l'enseignement - à la fois bien collectif et formation de capital humain - dans le raisonnement économique.

L'information de base utilisée pour effectuer cette analyse systématique provient des réponses à une enquête dont les objectifs essentiels étaient :

- passer en revue les caractéristiques générales des travaux consacrés à l'élaboration des modèles ; la nature et la portée de ces modèles dans les divers pays ;
- dégager les problèmes techniques importants rencontrés et les solutions apportées, en particulier pour l'estimation statistique des relations et la manière de les traiter pour obtenir des résultats valables ;
- tirer les leçons de l'exploitation de ces modèles dans le cadre de la planification ou de la prise de décision ;
- enfin, fournir à l'OCDE les éléments permettant de dégager les grandes orientations des travaux actuels et à venir consacrés à la construction des modèles dans le secteur de l'enseignement.

Pour réaliser cette enquête, un questionnaire très détaillé a été élaboré, comportant plus de cent questions, classées dans un organigramme logique, et dont les réponses (rassemblées par des enquêteurs spécialement préparés à cette tâche) étaient codées pour stockage et dépouillement sur ordinateur. Les rubriques de ce questionnaire portaient sur :

- la structure et le type du modèle ; ses variables et ses équations ; son horizon temporel ;
- la nature de son système d'équations et la méthode de résolution adoptée ;
- le cas échéant, des questions sur les modèles de programmation mathématique ;
- les techniques d'estimation des paramètres ;
- les caractéristiques particulières du modèle, et l'utilisation des résultats ;
- les questions demeurant en dehors du cadre des modèles explicites, portant sur les prévisions relatives aux effectifs, à l'offre et à la demande d'enseignants, aux coûts et aux ressources ;
- la position, au sein de l'administration, du service travaillant sur le modèle ;
- les relations de ce service avec d'autres organismes, et la coordination des projets communs ;

- le financement des organismes non gouvernementaux ;
- la responsabilité du service ; ses structures internes, ses fonctions, son organisation et sa formation.

Pratiquement tous les pays Membres de l'OCDE ont été touchés par l'enquête ; 122 modèles ont été analysés, dont 54 étaient, suivant les sources interrogées, encore en cours d'amélioration. Naturellement, la répartition par pays est très inégale, certains faisant état de plus de 12 modèles (Etats-Unis, Canada, Royaume-Uni, République fédérale d'Allemagne), ou d'au moins 6 modèles (Belgique, France, Irlande, Japon, Pays-Bas, Norvège). De plus, les modèles analysés sont de plus ou moins grande envergure, depuis la simple relation entre quelques variables jusqu'au modèle global incluant plusieurs sous-modèles. On a cependant éliminé de l'enquête les modèles portant sur des problèmes de caractère très particulier, comme la gestion d'une université, la prévision de la main-d'oeuvre si elle n'est pas reliée directement au secteur Enseignement, ou encore les modèles d'"apprentissage" étudiant diverses solutions pédagogiques.

C'est vraisemblablement la première fois que l'on procède à une enquête de ce type sur les modèles mathématiques du secteur Enseignement. Bien que l'enquête ait pu profiter de l'expérience d'enquêtes semblables dans le domaine de l'économie, la nature même du domaine exploré nécessitait l'élaboration d'un questionnaire particulier, dont la version simplifiée devrait permettre une mise à jour rapide des informations recueillies.

Première Partie

NATURE ET ROLE D'UN MODELE

II. CONCEPTS

On remarquera tout d'abord que si la psychologie, la sociologie ou la démographie, par exemple, peuvent être impliquées dans la construction de modèles pour le secteur Enseignement, c'est dans le domaine de l'économie appliquée qu'on trouve la principale source d'inspiration méthodologique : les expériences y sont en effet les plus nombreuses et, d'autre part, l'enseignement présente une composante de type économique dans le problème de l'utilisation optimale de ressources rares ; par ailleurs, sur un point particulier mais important, on rencontrera des modèles de même nature dans les deux domaines : les relations de passage entre les niveaux successifs de l'enseignement sont en effet analogues aux relations de type "input-output" qu'on établit depuis le modèle de Leontieff entre les secteurs productifs de l'économie.

Pour analyser, comparer et classer sans ambiguïté l'ensemble des modèles, il était nécessaire d'utiliser un vocabulaire bien défini pour chaque concept et ses emplois ; les éléments en ont d'ailleurs été précisés dès l'élaboration du questionnaire de l'enquête, et ils pourraient en fait constituer une base pour une typologie générale des modèles. Une première distinction permettra de préciser le concept général de modèle : il y a tout d'abord le modèle implicite où les estimations et les prévisions sont obtenues sans préciser de façon formelle leur interaction ou leur cohérence, en général à partir de jugements d'experts ; d'autre part, il y a le modèle explicite qui donne une représentation, en termes mathématiques, des relations liant deux variables ou plus, dont l'une au moins est ici relative à l'enseignement. C'est naturellement à ce dernier type de modèles qu'on s'intéresse essentiellement dans ce rapport, et il faut alors préciser le sens des quatre principaux éléments qu'on rencontrera à propos des modèles explicites :

- les variables : une variable est une expression mathématique (un symbole dans une équation) dont la valeur numérique n'est pas fixée ; une variable est "endogène" si sa valeur est déterminée comme solution des équations sous-jacentes au modèle, sinon elle est "exogène" ; parmi les variables exogènes, on appelle variable "contrôlable" (ou variable instrumentale) celle dont la valeur est laissée au choix du responsable de la décision ;

- les relations entre variables : ce sont en général des équations exprimant l'égalité de deux expressions ; les relations se distinguent individuellement par leur forme (par exemple : linéaire, non linéaire) et de façon globale dans le modèle ; "indépendantes" si elles ne présentent pas de liaisons entre elles, "récursives" si la solution de l'une dépend de la solution d'une autre, "simultanées" s'il faut les traiter ensemble pour déterminer leur solution ;
- l'estimation des paramètres qui mesurent l'intensité des liaisons entre les variables ; comme les variables exogènes, les paramètres sont déterminés de façon extérieure au modèle, en général par des méthodes statistiques d'estimation, mais parfois à partir de jugements d'experts ;
- les procédures de résolution : la solution du modèle, lorsqu'elle est unique, est définie par l'ensemble des valeurs des variables endogènes qui satisfont à toutes les relations ; lorsque la solution n'est pas unique, comme dans les modèles dits de programmation, on retient celle qui maximise une certaine "fonction-objectif".

Il faut enfin distinguer les modèles "stochastiques" où l'introduction d'éléments aléatoires est destinée à expliquer la distribution ou la dispersion du phénomène (indépendamment des aléas introduits pour justifier d'éventuelles estimations statistiques des paramètres) des modèles "déterministes" qui ne s'intéressent qu'au comportement moyen des phénomènes.

En dehors de ces concepts associés aux composantes de tout modèle explicite, il faut parler des "techniques" utilisées pour la construction de ces modèles. Leur nombre et leur diversité sont remarquables, et l'on pourrait en dénombrer une vingtaine qui sont usuelles dans cette branche de la science appelée "recherche opérationnelle". A titre d'exemples, citons les méthodes d'optimisation (dynamique ou non, linéaire ou non, etc.), les méthodes analytiques (simulation, théorie des files d'attente, etc.), la théorie de la décision (analyse numérique, statistique), la théorie des processus (processus stochastique, contrôle optimal), la théorie des jeux, les techniques analogiques, etc.

III. CLASSIFICATION

Pour prendre en compte les multiples différences dans la nature et le rôle des modèles, et pouvoir les distinguer selon les nombreuses techniques rencontrées, il a été nécessaire de définir un *système de classification* détaillé. Mais faute d'un cadre théorique universel dans lequel puissent s'inscrire tous les modèles du secteur Enseignement, ce système n'a pu être construit que sur une base empirique, après examen selon divers points de vue des caractéristiques des modèles de l'enquête, pour en déterminer les traits communs et les points de comparaison.

L'ossature de cette classification s'organise autour de quatre niveaux qui, du plus général au plus détaillé, s'emboitent de la façon suivante (cf. Tableau III.3., Chapitre III).

- les modèles sont classés tout d'abord selon 4 groupes de *caractéristiques* (l'objet du modèle, sa fonction, sa forme, son auteur) ;
  - A l'intérieur de chaque type de "caractéristiques", les modèles sont comparés selon divers points de vue appelés *dimensions* ;
    - Pour chaque "dimension" retenue, on les distingue selon une certaine liste de *catégories* ;
      - Et dans chaque "catégorie", on les classe selon leurs *éléments* (sous-catégories exclusives), et selon leurs *attributs* (chaque ~~modèle~~ pouvant avoir plusieurs attributs).

1. CARACTERISTIQUES CONCERNANT L'OBJET DU MODELE

Première dimension : *la PORTEE du modèle*

En classant les modèles selon leur portée, on distingue trois catégories suivant que le modèle concerne le secteur Enseignement seul, ou au contraire dans ses rapports avec les autres secteurs, ou enfin s'il ne concerne qu'une institution.

On distingue dans la catégorie des modèles concernant le *secteur Enseignement seul*, cinq "éléments" :

- les modèles globaux, qui intègrent en général plusieurs sous-systèmes ;

- les modèles de flux d'étudiants cheminant au sein du système ;
- les modèles paramétriques pour étudiants (étude des coefficients de passage) ;
- les modèles d'offre et/ou de demande d'enseignants ;
- enfin les modèles de ressources physiques et/ou financières.

Dans la catégorie des modèles liant le secteur Enseignement aux autres secteurs, on effectue le classement selon trois éléments :

- les modèles globaux des rapports de l'enseignement avec l'extérieur (économie générale) ;
- les modèles représentant les rapports entre l'enseignement et la main-d'oeuvre dans le système de production de l'économie ;
- enfin les modèles étudiant le rendement de l'enseignement, pour décider en particulier de la répartition des ressources.

Dans la catégorie enfin des modèles concernant une institution, on a classé, à titre d'exemples de ces travaux de nature micro-économique, certains modèles concernant soit la capacité du système, soit ses besoins de financement, soit sa productivité.

Deuxième dimension : le DOMAINE COUVERT par le modèle

On distingue deux catégories où classer le modèle, selon qu'il couvre l'ensemble du secteur Enseignement, ou au contraire ne concerne que certaines parties de ce secteur. Notons à ce propos l'intérêt de la classification croisée dans les deux premières dimensions selon le schéma ci-dessous :

Première dimension
PORTEE du modèle

		Secteur Enseignement seul	Enseignement relié aux autres secteurs
Seconde dimension DOMAINE COUVERT	Ensemble du secteur Enseignement		
	Partie du secteur Enseignement		

Troisième dimension : NIVEAUX D'ENSEIGNEMENT pris en compte

La troisième dimension permet de classer les modèles selon les niveaux d'enseignement introduits dans l'étude : il s'agit d'un découpage plus ou moins fin suivant le cas des trois niveaux : primaire, secondaire et supérieur.

Quatrième dimension : TYPES D'ENSEIGNEMENT concernés

Cette dernière dimension permet de classer les modèles selon les types d'enseignement qui constituent le centre d'intérêt de l'étude : enseignement professionnel, technique, général, formation d'enseignants, ou "autres types d'enseignement".

Quelques attributs possibles

Dans cette classification des modèles selon les caractéristiques concernant leur OBJET, on introduira d'autres points de vue comme autant d'"attributs" possibles des modèles : une classification selon les variables introduites : stock ou flux scolaires, stock ou flux d'enseignants, dépenses, stock de capital, coûts réels et monétaires, etc. ; une classification suivant la nature et la source des données : recensements, enquêtes spéciales, ou autres origines ; enfin une classification selon l'horizon de projection : court terme, moyen terme (5 à 7 ans) ou long terme.

2. CARACTERISTIQUES CONCERNANT LA FONCTION DU MODELE

Première dimension : le DESSEIN GENERAL du modèle

On distingue quatre catégories de modèles dans la classification fonctionnelle selon leur dessein général. Un modèle peut être "descriptif" ; on distingue alors deux sous-catégories, selon qu'il est purement descriptif ou également explicatif. Il peut s'agir par ailleurs d'un modèle essentiellement "prévisionnel", auquel cas on le classe suivant le degré de conditionnalité imposé aux prévisions : prévisions pures, projections conditionnées par des hypothèses de tendance, ou enfin projections dépendant de variables contrôlables. Dans une troisième catégorie on place les modèles de "décision", caractérisés par l'intérêt porté en premier lieu sur certaines variables contrôlables dont dépend la solution du modèle. Restent, dans une quatrième catégorie, les modèles de "simulation", stochastiques ou non, dont le but est de tester et d'expérimenter le comportement du système.

Deuxième dimension : les UTILISATIONS PARTICULIERES du modèle

Dans la classification fonctionnelle des modèles, cette seconde dimension est constituée d'un ensemble d'"attributs" (pas moins de 50) que peuvent ou non posséder les modèles dans chacune des quatre catégories précédentes. Ainsi par exemple un modèle purement descriptif peut ne concerner que la description du secteur Enseignement, ou s'attacher également à la description d'autre chose ; on fait la même distinction pour un modèle explicatif ; en ce qui concerne un modèle de prévision, on a catalogué 13 types de variables à projeter, etc.

3. CARACTERISTIQUES CONCERNANT LE MODE D'ANALYSE

Première dimension : l'ORIENTATION du modèle

On s'intéresse maintenant à la forme du modèle, c'est-à-dire à ses aspects techniques. En ce qui concerne l'orientation générale, on distingue trois catégories de modèles : (a) théoriques et algébriques ; (b) numériques et expérimentaux ; (c) numériques et appliqués (utilisant des données empiriques).

Deuxième dimension : la SIGNIFICATION FONDAMENTALE des équations

On utilise ici le vocabulaire proposé par Jan Tinbergen pour distinguer les équations de comportement, les relations technologiques, les relations juridiques ou institutionnelles, et enfin les équations comptables ou de définition.

Troisième dimension : la FORME des équations

On distingue six groupes d'attributs pour définir la forme mathématique d'une équation du modèle : égalité ou inégalité, stochastique ou non, retardée ou non, linéaire ou non, relative aux différences ou non, enfin discrète ou continue.

Quatrième dimension : la NATURE du SYSTEME des équations

Tout d'abord on isole les modèles d'optimisation (programmation) mathématique) en distinguant les modèles linéaires des modèles non linéaires. Ensuite les modèles sont classés selon la nature du système de leurs équations : indépendantes, simultanées, récursives par bloc, ou récursives.

Cinquième dimension : les TECHNIQUES d'ESTIMATION

Dans la catégorie des méthodes d'estimation des paramètres du modèle, on distingue plusieurs "éléments" : l'analyse statistique ou économétrique, les tableaux de données, les jugements d'experts et diverses autres méthodes. Dans la catégorie des techniques, on relève s'il s'agit de régression simple ou multiple, ou éventuellement d'une autre technique. Enfin une dernière catégorie concerne l'étude des valeurs des paramètres : stabilité des estimations dans le temps d'une part, et sensibilité des paramètres à des variations des variables.

4. CARACTERISTIQUES CONCERNANT L'ORIGINE DU MODELE

Première dimension :

Il s'agit de classer le modèle suivant l'affiliation de l'organisme qui le construit : on identifie sept types d'organismes :

- principaux organismes d'Etat chargés de l'enseignement,
- bureaux nationaux de statistiques,
- autres organismes d'Etat,
- les universités,
- autres organismes non gouvernementaux,
- les organisations internationales,
- les individus ne dépendant d'aucun des organismes cités.

Autres dimensions :

Des questions sont posées pour déterminer si les résultats du modèle sont ou non acceptés au niveau gouvernemental. On distingue ensuite les attributs des modèles suivant l'origine du financement de l'étude : Etat, université ou autre organisme indépendant. Enfin une dernière catégorie d'attributs concerne l'état d'avancement du travail.

IV. VUE D'ENSEMBLE

Parmi les 122 modèles recensés, on se propose de dénombrer ceux qui appartiennent à telle ou telle catégorie, ou ceux qui possèdent tel ou tel attribut dans chaque catégorie. Des dénombrements de cette nature doivent permettre d'apprécier, en première approximation, les caractéristiques essentielles de l'ensemble des rechercher sur les modèles mathématiques du secteur Enseignement. Mais les résultats doivent être analysés avec circonspection ; le dénombrement pur et simple des modèles cache en fait certains de leurs aspects : le modèle complexe incluant une centaine de variables et reliant l'enseignement à l'économie générale risque de n'y pas compter davantage que le simple exercice de régression entre deux variables.

Répartition des modèles selon leur OBJET (tableau IV-1)

La majorité absolue des 122 modèles est consacrée à l'étude du secteur Enseignement lui-même, sans liaison avec les autres secteurs : plus du tiers de ces modèles sont consacrés exclusivement à l'étude des flux scolaires. On relève ici un aspect important des recherches actuelles, tournées davantage vers la description des structures (tableau des coefficients de transition)que vers l'explication des comportements. Sur les 122 modèles, 37 s'attachent à relier le secteur Enseignement à d'autres secteurs, et parmi ceux-ci la moitié fait le lien avec les problèmes de main-d'oeuvre : le rôle de l'enseignement est encore très confiné à la production d'une main-d'oeuvre nécessaire. Enfin, on dénombre 18 des 122 modèles consacrés aux problèmes propres à une institution.

Recoupements entre OBJET et FONCTION (tableau IV-1)

Sur les 122 modèles, 57 sont essentiellement des modèles de prévision, 26 des modèles de décision, 24 des modèles de description ou d'analyse, et 15 seulement des modèles de simulation. Cette répartition globale de la fonction des modèles est assez différenciée suivant l'objet du modèle. En effectifs relatifs par exemple, les modèles globaux, les modèles d'offre et demande d'enseignants, et les modèles de flux scolaires du secteur Enseignement étudié pour lui-même, ainsi que les modèles liant l'enseignement à la main-d'oeuvre sont essentiellement des modèles de prévision ; les modèles de ressources du secteur Enseignement sont essentiellement tournés vers la décision tandis que les modèles des paramètres étudiants et les modèles de rendement de l'enseignement sont davantage orientés vers l'analyse et la description. Notons enfin que sur les 15 modèles de simulation, 6 sont des modèles institutionnels et 4 des modèles globaux inter-secteurs.

		FONCTION du modèle				
		description analyse	prévision	décision	simulation	
OBJET du modèle	Secteur Enseignement seul	11	35	16	5	67
	Inter-secteurs	7	19	7	4	37
	Institutions	6	3	3	6	18
		24	57	26	15	122

Point de recoupement de l'OBJET et du MODE D'ANALYSE (tableau IV-1)

Sur les 122 modèles, 106 sont des modèles numériques et expérimentaux ; 11 seulement sont des modèles considérés comme expérimentaux, et 5 considérés comme essentiellement théoriques. La prédominance des modèles considérés comme empiriques tient sans doute à la nouveauté de ce type de recherches où le processus de mise au point des modèles doit constituer une part importante des travaux.

Point de recoupement de l'OBJET et de l'ORIGINE du modèle (tableau IV-1)

Les auteurs des modèles sont à peu près également répartis dans trois catégories principales : les ministères de l'Enseignement, les autres services gouvernementaux et les universités ; 14 modèles ont été réalisés par des organismes non gouvernementaux, 2 seulement par les bureaux nationaux de statistiques et 4 par des organisations internationales. Notons une nette prédominance des modèles de ressources et des modèles d'offre et de demande d'enseignants dans les ministères de l'Enseignement ; tandis que les autres services gouvernementaux s'intéressent plus particulièrement aux modèles inter-secteurs globaux et aux liaisons avec la main-d'oeuvre, on trouve naturellement dans les universités une prédominance de modèles institutionnels.

Les attributs concernant l'OBJET du modèle (tableau IV-2)

Dans la classification des modèles selon leur objet, les attributs qui les distinguent concernent essentiellement la nature des variables qui sont prises en compte ; notons que, sur les 122 modèles :

- 11 seulement ne contiennent aucune variable relative aux étudiants,
- par contre 59 ne contiennent aucune variable relative aux enseignants,
- il y a 67 modèles qui ne contiennent aucune variable relative soit aux coûts, soit aux dépenses.

De l'aspect du tableau IV-2, on retiendra essentiellement que la plupart des modèles intègrent des variables d'étudiants et d'enseignants (avec prédominance des stocks sur les flux), mais accordent moins d'attention aux variables économiques (sauf lorsqu'il s'agit de l'enseignement supérieur).

Les attributs concernant le MODE D'ANALYSE (tableau IV-3)

On recoupe les modèles selon leurs fonctions d'une part, et la nature de leurs relations d'autre part : sur 110 modèles pour lesquels on a des informations, 62 seulement contiennent des relations de comportement (13 d'entre eux ne contiennent que des relations de ce type) ; ce fait renforce l'hypothèse que l'approche structurelle joue un rôle prédominant dans la construction des modèles pour l'enseignement. Les modèles de décision et de simulation apparaissent particulièrement dépourvus de relations de comportement.

En établissant le recoupement des modèles selon leur fonction d'une part, et selon la forme de leurs relations d'autre part, on remarque que seuls 29 modèles ne contiennent pas de relations linéaires, la plupart dans la catégorie des modèles de description ou d'analyse. Si les relations sont linéaires, elles constituent en général un système indépendant ; d'ailleurs, sur 108 systèmes d'équations, 49 sont des systèmes indépendants, essentiellement dans la catégorie des modèles de prévision. C'est sans doute la nouveauté de ces recherches qui est cause de la simplicité relative des traitements : relations linéaires et systèmes indépendants.

Les attributs concernant la FONCTION du modèle (tableau IV-4)

Le tableau IV-4 recoupe les 51 attributs affectés à la classification fonctionnelle des modèles (dans les catégories : description, projection, décision et simulation) d'une part, avec, d'autre part, leur répartition selon le niveau d'enseignement concerné.

Dans la catégorie des modèles de projection, on trouve 32 modèles pour prévoir les inscriptions et 26 pour prévoir les effectifs de diplômés ; 18 pour prévoir les nouveaux entrants et 15 pour prévoir les abandons ; enfin 15 pour prévoir les disponibilités de main-d'oeuvre. La plupart de ces modèles concernent tous les niveaux d'enseignement simultanément, ou encore l'enseignement supérieur seul, ainsi que le groupe primaire-secondaire (où l'accent est mis sur l'offre et la demande d'enseignants). On ne trouve que 10 modèles de prévision des coûts ou des dépenses.

Dans la catégorie des modèles de décision, il est assez étonnant de constater que la plupart des modèles traitent de décisions partielles plus que globales ; ils sont consacrés le plus fréquemment aux problèmes d'allocation de ressources physiques et/ou financières (en particulier dans l'enseignement supérieur, et dans le groupe primaire-secondaire).

Les modèles de simulation concernent essentiellement soit tous les niveaux simultanément, soit l'enseignement supérieur seul, et étudient en particulier les effets des inscriptions sur les coûts et les besoins d'enseignants. Enfin, dans la catégorie des modèles descriptifs ou explicatifs, la majorité des modèles concernent l'enseignement supérieur.

Deuxième Partie

DESCRIPTION DES MODELES

V. OBJET DES MODELES

1. MODELES DE FLUX SCOLAIRES

Le coeur de ces modèles est le tableau des flux scolaires (figure V-1) retraçant le cheminement de l'ensemble des élèves inscrits dans chaque branche d'enseignement entre deux années consécutives. Ce tableau se subdivise en deux sous-tableaux :

1. un tableau carré représentant le cheminement des élèves à l'intérieur du système d'enseignement;
2. un tableau représentant les élèves qui quittent l'école (abandon avec ou sans diplôme).

Il s'agit avant tout d'un outil comptable permettant de suivre dans un cadre cohérent les mouvements des élèves d'une année sur l'autre; il faut savoir que, d'un point de vue statistique, son élaboration n'est généralement pas une opération simple.

En supposant que tous les coefficients de transition inscrits dans le tableau restent constants au cours de la période étudiée, et en appliquant cette matrice de passage aux générations successives inscrites dans le système, on analyse les répercussions des facteurs démographiques sur les effectifs futurs d'inscrits et de diplômés. Lorsque cette procédure est appliquée, on dit que le modèle repose sur une "hypothèse de constance".

Cependant, outre l'effet des facteurs démographiques, les effectifs et la production de l'enseignement peuvent subir l'influence de décisions de politique prises en matière d'enseignement, traduites par une modification dans le temps des coefficients de transition de la matrice. On réalise dans ce cas un "modèle dynamique de passage" où l'utilisation de coefficients dynamiques de transition se traduit par l'emploi de matrices de passage différentes pour chaque transition entre deux années de la période de planification (à la fois pour les coefficients de redoublement, de progression, d'abandon et ceux de sortants diplômés).

On peut utiliser les matrices dynamiques de passage pour déterminer comment les objectifs choisis pour la période de planification se répercuteront sur les effectifs inscrits et promus au cours de cette période. Pour ces "modèles à objectifs fixés", la matrice de passage correspondant à l'année finale du plan reflète en fait les objectifs de planification qu'on a choisis; les matrices de la période intermédiaire seront constituées par l'ensemble des tableaux dont les éléments progressent à un taux annuel constant sur la période du plan (mais on ne saurait rendre justice en si peu de mots à l'intérêt et à la puissance de l'outil d'analyse que constituent les tableaux de flux).

2. DESCRIPTION DE L'OBJET DES MODELES

Les modèles globaux pour l'enseignement

Parmi les six modèles recensés dans cette catégorie, le mieux documenté est sans doute celui de R. Stone (2)* décrivant et projetant les diverses composantes du système en fonction de nombreux facteurs. La "London School of Economics - Higher Education Research Unit" (3) travaille sur un modèle global de prévision. On trouve aux Etats-Unis une étude méthodologique (4) sur l'évolution du système d'enseignement; en Allemagne (1), un modèle global servant à la prévision des dépenses; un modèle de simulation global (6) assez éloigné des problèmes concrets; et enfin en Yougoslavie une étude sur les réformes du système, basée sur la méthode PERT.

Les modèles de flux scolaires

Les modèles canadiens (11,12), allemand (7), islandais (18), irlandais (16) et belge (10) utilisent des matrices de transition plus ou moins standards. Dans le modèle écossais (22), on prend en compte certaines évolutions temporelles et on utilise des variables de contrôle (en mettant l'accent sur l'enseignement supérieur). Le modèle américain (13) sera analysé plus loin.

Les modèles paramétriques pour étudiants

Le modèle (31) consacré à l'enseignement supérieur est un modèle semestriel où les effectifs d'étudiants sont ventilés selon

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* Les chiffres entre parenthèses dans le texte renvoient au numéro d'identification de chaque modèle dans la liste figurant en annexe (publication séparée).

12 disciplines. Le modèle allemand (51) est un modèle de prévision où les paramètres d'étudiants jouent un grand rôle dans la mesure où l'on étudie les facteurs déterminant les taux de passage. Le modèle français (36) fait une étude approfondie de l'effet des variables démographiques et sociologiques sur le taux de progression des élèves. Le modèle du Pr. Barnard (37) étudie les passages du secondaire au supérieur ou à la vie active, selon les caractéristiques combinées des établissements et des élèves; enfin, le modèle américain (33) est consacré à la demande d'enseignement supérieur en fonction de divers facteurs.

Les modèles de demande et d'offre d'enseignants

Ces modèles se ressemblent beaucoup dans leur structure. La demande d'enseignants y est déterminée par deux séries de facteurs: les données démographiques - citons par exemple les modèles (38), (39), (46) ou (47) - et l'organisation de l'enseignement: par exemple le modèle (43). Le modèle (44) est un modèle de répartition optimale des enseignants entre universités.

Les modèles de ressources

Dans une première catégorie, on trouve des modèles globaux étudiant les coûts: (51), (63), (64), (65) et (67) par exemple. Une autre catégorie est consacrée à l'étude des subventions: (55), (56) et (66). Enfin on trouve les modèles consacrés à l'implantation des écoles, comme le modèle belge (52), et les modèles (53), (54), (60) et (61).

Les modèles des rapports de l'enseignement avec l'extérieur

Le modèle canadien (89) et le modèle français (91), les modèles japonais (97, 98, 99) et norvégien (93) se placent dans l'optique de la main-d'oeuvre. Les modèles établissant le lien entre l'enseignement et l'économie générale utilisent généralement des méthodes assez semblables; citons les modèles (68), (69), (72), (74), (75), (76), (77), (78), (82). Le modèle (104) est consacré à l'étude du rendement de l'enseignement.

Les modèles institutionnels

Les plus simples sont les modèles étudiant la capacité du système, comme les modèles (105), (106) et (109). Parmi les modèles étudiant les besoins en ressources, citons (110) et (111), (117), (112), (113), et (116). Un troisième groupe comprend les modèles mesurant la productivité d'un établissement d'enseignement: (112), (115), (119) et (120) par exemple, font partie de cette catégorie.

3. LES MODELES DE PROGRAMMATION

On dénombre une douzaine de modèles procédant de la technique de programmation linéaire. Certains sont consacrés à la détermination de l'implantation optimale des établissements d'enseignement: (52), (54) et (61). Mais les plus intéressants sont sans doute ceux où la fonction à maximiser est de nature moins technique et appelle des justifications: répartition optimale des nouveaux inscrits (21); minimisation du coût associé à la variation d'un taux de transition (68); optimisation du temps d'enseignement (40); maximisation de la consommation ou minimisation du chômage (71); maximisation d'une fonction, de préférence collective (72). Ces deux derniers modèles sont conçus pour conduire à la formulation d'une politique de l'enseignement; bien que procédant d'une approche différente, ils présentent de nombreux points communs, et posent clairement le problème de l'évaluation de la fonction objectif dont l'impact peut être déterminant pour la valeur de la solution du modèle.

VI. ASPECTS TECHNIQUES

Exemples de procédures de prévisions scolaires

Rappelons que la prévision, et surtout la prévision à long terme, est le sujet prédominant des modèles recensés par l'enquête. On trouvera ci-dessous plusieurs exemples illustrant les meilleures méthodes actuellement utilisées pour la prévision des effectifs scolaires.

1. "Prévisions des effectifs universitaires en Belgique"(10). Il s'agit de prévisions à long terme, ventilées par université, par sexe et par faculté, et reposant toutes sur les tendances passées. Il existe quatre systèmes alternatifs d'équations traduisant la nature de l'accroissement annuel des effectifs, aucun ne faisant intervenir la notion de flux.

2. "Modèle de prévision à long terme pour le système d'enseignement néerlandais" (77). Le modèle prévoit les effectifs

scolaires tous les dix ans jusqu'en 1999, à partir de l'extrapolation des taux de scolarisation observés depuis 1850.

3. "Modèle de prévision des étudiants prenant un premier emploi" (83). Ce modèle couvre l'ensemble de l'enseignement à plein temps et établit des prévisions pour 1975. Les coefficients de transition et les effectifs universitaires sont considérés comme variables de politique.

4."Le modèle américain de l' Office of Education" (4) projette le nombre des inscrits à tous les niveaux de l'enseignement, ainsi que le nombre des diplômés des High Schools et le nombre de diplômés, par discipline, à partir de projections linéaires de statistiques démographiques.

5. "Démonstration de l'application de la technique d'analyse de cohorte pour une prévision des effectifs d'étudiants et des diplômes acquis dans l'enseignement supérieur" (13). Le modèle établit des projections allant jusqu'en 1984; il apparaît particulièrement intéressant par le soin apporté à son élaboration et à l'explicitation des hypothèses de la méthode.

6. "Flux d'étudiants dans le système d'enseignement britannique" (3). Le modèle concerne essentiellement le passage du secondaire au supérieur, et utilise trois méthodes différentes pour effectuer les prévisions, toutes cependant consistant à calculer l'effectif de population "susceptible" d'entrer à l'université, et non y entrant effectivement.

7. "Modèle démographique de type "input-output" pour la prévision dans l'enseignement" (5). Ce modèle comporte un tableau "input-output" utilisant l'âge des étudiants comme pôle de la matrice de comptabilité démographique, et ne peut donc être utilisé que pour des prévisions par groupe d'âge. On notera l'originalité de cette démarche.

Modèle à équations simultanées

Prenons comme exemple le modèle PARTI (121); il utilise la régression linéaire multiple pour établir un système d'équations simultanées d'offre et de demande où les effectifs d'enseignants ainsi que trois mesures de qualité d'enseignement sont fonction des caractéristiques de l'école et de l'environnement ainsi que des niveaux de salaire. Il s'agit d'étudier l'emploi d'une fonction de production (linéaire) de l'enseignement pour déterminer la meilleure combinaison des "inputs" d'un système d'enseignement. Un aspect intéressant de ce modèle est la prise en compte de l'interdépendance entre certaines des variables, et l'introduction des variables de prix (salaires) qui rend la fonction à maximiser non linéaire en terme de variable instrumentale (ce qui conduit à une productivité marginale non constante). A l'époque de l'enquête, ce modèle n'avait pas encore de résultats numériques.

Estimation des paramètres et test des modèles

Les paramètres des modèles peuvent être estimés de diverses façons. On trouve par exemple l'analyse de tableaux de données dans les modèles (15) et (30); dans les modèles de simulation, il y a prédominance d'estimation par jugement d'experts: (41), (51), (56), (66); cependant, c'est l'analyse statistique-économétrique qui offre le champ d'application le plus vaste en matière d'estimation des paramètres. Suivant la masse des données disponibles, on s'efforce d'estimer non seulement les paramètres eux-mêmes (sur des coupes transversales), mais éventuellement leur évolution dans le temps (sur la base de séries chronologiques): c'est le cas des modèles (9) et (72). Quoi qu'il en soit, les méthodes de régression simple et multiple sont les plus utilisées pour réaliser ces estimations.

Cependant, les méthodes statistiques d'estimation utilisées dans certains modèles reposent souvent sur des hypothèses a priori (de constance, ou de variation constante) qui ne sont pas exemptes de critiques, et d'autre part l'usage qui est fait des estimations n'est pas toujours compatible avec les propriétés qu'elles possèdent du fait même de la façon dont elles ont été obtenues.

Dans la catégorie des modèles descriptifs ou explicatifs, dont les deux tiers utilisent la procédure de régression dans le calcul de leur solution, les estimations sont effectuées essentiellement sur une base statistique ou à partir de tableaux de données. On y trouve cependant d'autres méthodes d'estimation, comme les techniques d'analyse à variables multiples, dont le modèle (34) donne des exemples (analyse discriminante).

En ce qui concerne le test des modèles, l'analyse de sensibilité aux variations des paramètres semble être assez peu employée. On trouve cependant des exemples d'expériences de nature différente : sensibilité aux variations des coefficients d'une fonction-objectif dans les modèles (72) et (65); sensibilité à des variations simultanées de nombreux paramètres dans les modèles(1) ou (31); ou au contraire sensibilité à la variation d'un ou de quelques paramètres jugés fondamentaux, comme dans le modèle (8).

On remarque également que les procédures de test et de validité des résultats des modèles sont assez peu fréquentes, et leur absence est certainement regrettable dans les modèles de prévision. Comme palliatif, on trouve parfois le procédé consistant à comparer plusieurs résultats obtenus par des méthodes différentes, comme dans (1) et (13). Tester la validité d'un modèle est naturellement une procédure plus difficile à concevoir dans le cas de modèle de décision ou de simulation. Signalons enfin le recours fréquent à l'ordinateur pour effectuer les calculs requis, soit pour l'estimation, soit pour la solution des modèles mathématiques du secteur enseignement.

VII. ETUDE DE CAS

1. MODELE NORVEGIEN DE PREVISION DES INSCRIPTIONS

Le modèle (12) concerne la prévision des inscriptions et des résultats dans le système d'enseignement norvégien post-secondaire, sans le relier au secteur économique ou à la main-d'oeuvre; il calcule des solutions alternatives suivant une batterie d'hypothèses sur les taux futurs de participation, de transition et d'abandon.

L'ensemble des équations du modèle, au nombre de 4.876, constitue un système récursif; il y a 36 équations de type "institutionnel" et parmi les 4.840 autres relations, considérées comme relations de "définition", on en dénombre 1.396 concernant les inscriptions. Environ les deux tiers des relations sont "instantanées", les autres étant à retard échelonné (et pour la plupart de rang 1). Les estimations des paramètres des équations ont été obtenues soit à partir de tableaux de statistiques, soit par des procédures économétriques, mais ont parfois été rectifiées subjectivement (sans doute à la suite de tests de validité des résultats). Les prévisions calculées avec ce modèle ont été acceptées au niveau gouvernemental et sont utilisées pour estimer les dépenses futures des universités.

Signalons, parmi les hypothèses critiquables du modèle, la non prise en compte des redoublants d'une part, et d'autre part la non prise en compte des nouveaux inscrits en dehors du premier niveau. De plus, les chiffres mériteraient d'être corrigés par le taux de mortalité et toute autre cause d'inactivité éventuelle des étudiants. Mais la faiblesse la plus grave de ce modèle est sans doute l'absence de toute relation de "comportement": le modèle n'explique pas le comportement des variables du système d'enseignement, mais repose entièrement sur des relations de flux déterminées dans le passé. Il n'y a aucune indication sur les raisons qui sont à l'origine des variations dans les valeurs des coefficients. On notera par contre l'intérêt accordé à l'analyse de la sensibilité de certains des coefficients parmi les plus importants.

2. UN MODELE POUR LE SYSTEME D'ENSEIGNEMENT ALLEMAND (30)

Il s'agit d'un modèle de simulation concernant le système d'enseignement de la République fédérale d'Allemagne, depuis le pré-primaire jusqu'aux universités, tenant compte des interdépendances. Le modèle peut être utilisé comme instrument de décision pour l'évaluation de politiques alternatives concernant l'enseignement; sa structure complexe nécessite l'emploi d'un ordinateur pour engendrer les données.

Au coeur du modèle se trouve un modèle de flux scolaires représentant les mouvements des élèves et étudiants au sein du système. Les résultats de ce modèle, effectifs d'élèves et d'étudiants,par période sont ensuite répercutés dans trois autres modèles complémentaires:

- un modèle concernant les enseignants où sont déterminées et équilibrées l'offre et la demande d'enseignants dans les diverses catégories;
- un modèle des besoins en surface déterminés en mètres carrés par la différence entre la demande en fin de période et les disponibilités en début de période;
- enfin un modèle financier qui analyse les conséquences financières des résultats du modèle de flux scolaires, du modèle pour les enseignants et du modèle pour les surfaces. Le coût total est confronté à la part du PNB consacrée à l'enseignement.

La première version de ce modèle est achevée, mais l'étude doit être poursuivie soit en raffinant les classifications (par région), soit au contraire en agrégeant; d'autre part on cherchera à rendre cohérent ce modèle avec d'autres modèles (le marché du travail par exemple), et enfin en le généralisant pour son application à d'autres pays du Marché Commun.

3. MODELES AVEC RELATIONS DE COMPORTEMENT

Le modèle GIRARD (36)

Le modèle est descriptif et montre les progrès d'une cohorte de quelque 17.000 élèves suivis de 1962 à 1966, depuis leur sortie de l'enseignement primaire. Les élèves sont classés par sexe, catégorie socio-professionnelle du père, taille de l'agglomération, type de programme choisi, type d'école, âge et retard, et jugement du professeur à la sortie du primaire. Les résultats des observations sont intéressants, mais les dépendances et corrélations qu'on y découvre peuvent difficilement être interprétées en terme de causalité, ou généralisées à toute la population scolaire.

Le modèle TANGUY (35)

Le modèle cherche à expliquer les différences de taux d'inscription dans le second cycle (11 à 14 ans) entre les départements français. L'information repose sur un questionnaire rempli par les parents; les variables les plus intéressantes sans doute concernent le département et ses caractéristiques sociales, économiques et démographiques. L'introduction de deux variables particulières, les années de scolarité et le nombre de places disponibles, permettrait d'en faire un modèle d'étude de politiques pour l'enseignement. S'il s'agissait au départ d'étudier l'application d'une certaine réforme administrative, le modèle trouve, en fait, un autre intérêt dans l'étude des besoins, au niveau régional, grâce à l'introduction des variables économiques départementales.

Le modèle LGORU (Local Government Operational Research Unit) (24)

L'étude est consacrée à la recherche des facteurs expliquant le pourcentage d'élèves restant dans le secondaire jusqu'à un âge donné. Il y a trois catégories de variables explicatives: les caractéristiques du contexte (relatif à la composition de la population, taille des familles, etc.), l'environnement scolaire et l'organisation propre à l'établissement, enfin les caractéristiques de l'emploi. Il s'agit pourtant essentiellement d'un modèle de prévision qu'on pourrait qualifier de conjectural car les variables "explicatives" sont sélectionnées sur leur "performance";

cependant on trouve certaines variables qui pourraient être considérées comme instrument de politique pour l'enseignement.

Le modèle ORR (3)

Il s'agit d'un modèle étudiant la dépendance des coefficients de transition dans le secondaire (supérieur) sur la base de facteurs socio-économiques et ce à partir des résultats d'une enquête. La technique utilisée est l'analyse de la variance "pas-à-pas" sélectionnant les variables indépendantes dans l'ordre de leur contribution à l'explication des variances des variables endogènes (mais l'existence de multicolinéarités soulève des difficultés d'ordre méthodologique). Il s'agit davantage d'un modèle de prévision que d'un modèle descriptif, qui d'ailleurs n'étudie pas les variations des coefficients de liaison entre les variables.

Le modèle BARNARD (37)

Le modèle étudie les facteurs influençant les choix dans l'enseignement supérieur à partir des résultats d'une enquête. Les variables exogènes concernent les caractéristiques familiales, les préférences de l'élève et les caractéristiques des écoles. Il s'agit d'un modèle descriptif, ne comportant aucune variable de politique.

Le modèle PERL (34)

Le modèle essaie de déterminer les effets sur les taux de succès des dépenses d'enseignement et des caractéristiques familiales (enquête du "Project Talent"). Il présente un grand intérêt méthodologique dans sa formulation (fonctions de production de l'enseignement interdépendantes). Son but est essentiellement de fournir des critères pour décider des ressources et des admissions, mais il pourrait être employé également pour projeter les taux de succès.

Le modèle HOENACK (59)

Il s'agit de mesurer la demande dans divers types d'enseignement supérieur en fonction des coûts d'une part, et du niveau de revenu de la famille de l'étudiant d'autre part. Le modèle comporte diverses fonctions-objectifs non linéaires des planificateurs dans un système d'équations non linéaires. Il s'agit essentiellement d'un modèle de décision.

Le modèle PANOS-ASTIN (58)

Le modèle établit des prévisions du taux d'abandon dans l'enseignement supérieur (à partir d'une banque de données américaine). Il utilise les techniques de régression linéaire multiple sur un grand nombre de variables exogènes concernant soit les caractéristiques extra-universitaires, soit des caractéristiques définissant l'environnement universitaire. Il s'agit d'un modèle essentiellement descriptif, dont les résultats actuels sont assez peu satisfaisants.

Le modèle O'BRIEN-ZINTER (122)

Il est conçu pour étudier la liaison entre l'effectif des étudiants dans une certaine institution et diverses mesures de la qualité de cette institution. La technique utilisée est la régression linéaire multiple, et la nature des résultats obtenus permet de classer ce modèle parmi les modèles de décision.

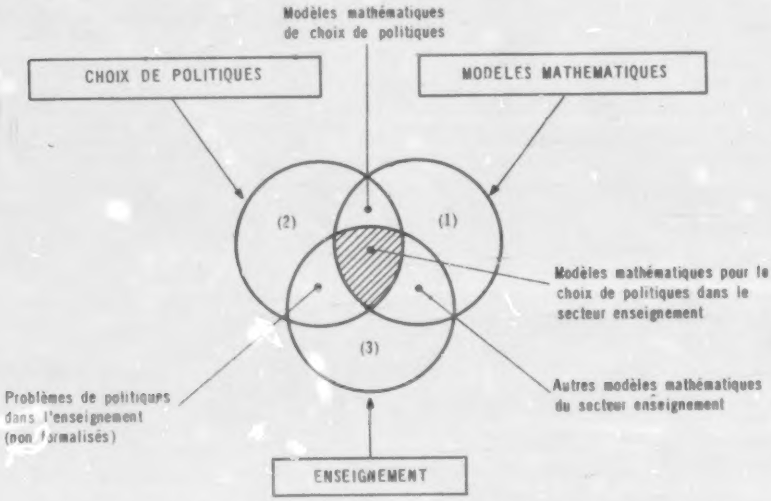
Troisième Partie

PROBLEMES ET OBJECTIFS

VIII. PROBLEMES DE POLITIQUE DE L'ENSEIGNEMENT

1. UN CADRE ANALYTIQUE

Pour discuter systématiquement les problèmes de définition de politiques dans le secteur Enseignement et les relier aux objectifs des modèles mathématiques, on se propose de fixer un cadre analytique permettant de situer chaque problème spécifique dans un contexte conceptuel général. Le schéma ci-dessous illustre la naissance, par intersection de trois concepts fondamentaux, des objets qui nous intéressent: les modèles mathématiques (1er ensemble) concernant les choix de politiques (2ème ensemble) dans le secteur de l'enseignement (3ème ensemble):


Modèles mathématiques de choix de politiques
CHOIX DE POLITIQUES
MODELES MATHEMATIQUES
(2)
(1)
(3)
Modèles mathématiques pour le choix de politiques dans le secteur enseignement
Autres modèles mathématiques du secteur enseignement
Problèmes de politiques dans l'enseignement (non formalisés)
ENSEIGNEMENT

Ainsi l'analyse de la signification et des finalités associées au choix d'une politique sera suivie du problème des frontières de l'enseignement, puis de la relation entre le choix d'une politique d'une part, et les aspects du secteur Enseignement couverts par les décisions de politique d'enseignement, d'autre part.

On donne ici au mot "politique" un sens restreint: il s'agit de l'adoption d'une règle de décision plus ou moins automatique applicable. toutes choses égales par ailleurs, sous certaines conditions fixées. Ainsi on ne parlera pas de "politique" à propos de décisions concernant des événements uniques; par contre, une "politique" peut naître ex-post, et de façon pratiquement involontaire, à propos de décisions répétées continuellement dans des conditions semblables et conduisant à contrôler ou influencer une certaine situation. A propos de politique, on distinguera les buts de la politique (la plupart du temps, des "variables-objectifs"), et les instruments de cette politique (les variables sous le contrôle du décideur); c'est par manipulation des variables instrumentales qu'on tente de réaliser les objectifs de la politique.

La définition des frontières de l'enseignement est délicate; elles débordent certainement les enceintes des institutions destinées par nature à l'enseignement, et par ailleurs il est difficile de séparer ce qui, dans la "production" de l'enseignement, ne serait que l'effet du secteur Enseignement proprement dit (penser aux facteurs socio-économiques par exemple). Où que l'on place les frontières, il est encore nécessaire de définir la structure de l'enseignement: organisation hiérarchique des niveaux, organisation administrative, etc. Les problèmes associés à ce schéma structurel du système ne pourront pas être disjoints de considérations plus générales (penser par exemple à la formation permanente).

Quant au choix d'une politique pour l'enseignement, il faut le considérer en terme de règles de décision appliquées aux phénomènes qui tombent dans les limites des frontières du secteur Enseignement. (On a déjà rencontré une catégorie de modèles mathématiques pour l'enseignement qui concernent les problèmes de choix d'une politique: ce sont les modèles dits de décision). Ainsi peut-on distinguer deux niveaux d'analyse: d'une part, l'étude de l'enseignement en tant que système global (schéma structurel du système et ses objectifs); d'autre part, l'étude des politiques d'enseignement où l'accent est mis sur les relations entre instruments et objectifs.

2. SCHEMA STRUCTUREL DU SYSTEME ET PROBLEMES DES POLITIQUES

On trouve en présence, d'un côté les problèmes associés au schéma structurel du système avec l'ensemble de ses objectifs, et de l'autre les modèles mathématiques avec leurs techniques quantitatives inspirées de la recherche opérationnelle; il serait nécessaire d'introduire ici des concepts qui permettent de faire la liaison entre ces deux points. Il serait opportun de parler à ce propos d'une science des politiques (en anglais "Policy Science"), en reprenant ce titre d'une nouvelle revue anglo-saxonne, où le mot désigne l'application du raisonnement, de l'analyse systématique et de connaissances multidisciplinaires aux problèmes du choix des politiques en matière de services publics. Les développements de cette science devraient être suivis avec intérêt, en particulier pour l'essor des modèles dans le secteur Enseignement où ils trouveraient des applications non seulement au niveau global, mais même au niveau du micro-comportement.

Même s'il existe effectivement des techniques et des modèles permettant d'appréhender le problème du choix de politiques particulières concrètes, un écart subsiste entre ces techniques et les problèmes généraux d'analyse de système et de spécification de finalités et de priorités. Sans doute faudrait-il commencer par décrire, de façon empirique et approximative, ces diverses priorités et hiérarchies dans les objectifs; l'analyse par thème et l'analyse de contenu qui vont suivre devraient y contribuer.

3. ANALYSE DES FINALITES

L'analyse par thème

On a divisé les finalités de l'enseignement en trois types: celles concernant la définition d'une politique de l'enseignement, celles concernant la structure du système, et les autres. Pour faire l'inventaire de ces finalités, on a utilisé les réponses à une enquête menée par l'OCDE auprès des pays Membres (au début de 1970); on a retenu 10 finalités par pays qu'on a ensuite classées dans les trois catégories précédentes (au total environ 200 finalités ont été ainsi répertoriées). Finalement on a retenu une liste de 10 rubriques concernant les finalités, exprimées en termes généraux; en particulier une des priorités apparaît comme étant le rendement de l'enseignement analysé par des études de bénéfice-coût; une autre, la formation permanente, etc.(On trouvera dans le texte une liste détaillée par pays).

L'analyse de contenu

Il s'agit d'une technique appliquée à la description statistique ou à l'analyse systématique du contenu d'une communication, et ceci en affectant des fréquences numériques aux catégories décrites par l'analyse (on compte les répétitions de mots, les phrases, les rubriques, le nombre de lignes, etc.). Le texte présente un exemple d'application de cette technique au problème des finalités de l'enseignement. Ces analyses ne sont malheureusement pas exemptes de critiques sérieuses: comment faire la part des effets dus à la présentation des questions, à la personnalité des personnes interrogées, à la représentativité de l'échantillon ? On peut cependant penser que les résultats d'une telle analyse de contenu, menée auprès des autorités gouvernementales pour étudier les finalités de l'enseignement, pourraient être utilisés comme information pour tester les liaisons entre ces objectifs et les buts assignés aux modèles mathématiques dans le secteur Enseignement.

Une autre utilisation possible des résultats d'une analyse de contenu serait la comparaison des contenus entre pays, en utilisant les données fournies par l'analyse: on établirait des classements d'un pays à l'autre, par ordre de priorité, plutôt que des mesures obtenues par pondération des variables-objectifs. Enfin la technique pourrait être utilisée pour étudier, dans chaque pays, ce qu'apporte l'analyse pour la comparer aux données fournies par d'autres sources (comme par exemple les modèles mathématiques du secteur Enseignement).

IX. LA RAISON D'ETRE DU MODELE

1. POURQUOI DES MODELES?

Que ce soit de façon consciente ou non, la raison d'être des modèles dépasse souvent les objectifs purement analytiques qu'on leur donne. C'est pourquoi il est bon de s'interroger sur les usages qu'on peut *a priori* assigner à un modèle. On peut en dresser une première liste en trois catégories:

A propos de définition d'une politique:

1) instrument d'aide à la décision,
2) résolution de problèmes spécifiques,
3) planification et contrôle,

4) réduction de l'arbitraire dans les décisions,
5) résolution de conflits,
6) discussion de solutions alternatives;

A propos d'analyse:

7) recherche de cohérence,
8) support d'information,
9) approximation d'un phénomène réel,
10) représentation idéalisée,
11) image partielle et "maquette" de la réalité
12) étape pour éclairer un phénomène;

Autres propos:

13) arme idéologique,
14) instrument pédagogique,
15) piège ou leurre délibéré.

Les objectifs des modèles mathématiques du secteur Enseignement tombent dans l'une ou l'autre des deux premières catégories: définition d'une politique ou analyse; mais ils peuvent avoir d'autres raisons d'être que celles explicitement citées par leurs auteurs: pour en décider, il faudrait analyser les motivations qui sous-tendent les efforts menés pour la construction des modèles.

2. UNE LISTE DES OBJECTIFS EXPLICITES

On trouvera dans le texte une liste des objectifs explicitement affectés aux modèles, tels qu'ils apparaissent dans les réponses de l'enquête. Bien que ces réponses aient été la plupart du temps rédigées par les enquêteurs, elles demeurent souvent imprécises et donnent une image peu fidèle de l'orientation réelle des modèles telle qu'elle apparaît après examen du modèle lui-même - ce qui malheureusement introduit une distorsion assez importante dans cette analyse.

3. DU CHOIX D'UNE POLITIQUE AUX RAISONS D'ETRE DES MODELES

La confrontation des objectifs explicitement énoncés des modèles avec les finalités spécifiques de l'enseignement annoncées par les responsables fait apparaître la faille existant dans les efforts consacrés actuellement à la construction des modèles. Cette faille qu'on a décelée mériterait une étude plus approfondie au niveau de chaque pays, étude qui pourrait être menée par une tierce personne neutre et compétente.

En première approximation il est cependant intéressant d'essayer de mettre en correspondance, à partir de nos informations, les desseins des modèles et les finalités de l'enseignement dans chaque pays; un classement international aurait été également possible et souhaitable pour étudier la possibilité de transférer d'un pays à l'autre certains modèles en fonction de leur usage. Dans le tableau des correspondances obtenues, on peut trouver l'existence de modèles apparemment adaptés aux problèmes soulevés par les responsables du secteur Enseignement du pays considéré. Cependant l'existence de ces appariements ne garantit pas l'adéquation du modèle à la solution du problème, ne serait-ce qu'à cause des imprécisions de nos informations pour réaliser ces appariements.

X. CONCLUSION

1. RESUME

Après avoir fait une analyse agrégée des modèles de l'enquête, et montré leur distribution dans la classification adoptée, on a effectué une étude des modèles par sujet et par caractéristiques structurelles: trois exemples seulement ont été traités en détail. Enfin on vient d'essayer de mettre en correspondance les desseins explicites des modèles avec les principales finalités reconnues dans chaque pays pour le secteur Enseignement. On résumera la substance de ce rapport, à partir des quelques dichotomies rencontrées au cours de ce travail:

Structure/comportement

Il est clair que le point de vue structuraliste prévaut, comme le prouve le nombre de modèles de flux scolaires, et ceci en particulier dans l'Europe de l'Ouest: les facteurs influant sur les coefficients de transition entre niveaux sont en général déterminés en dehors du modèle. On trouve peu d'intérêt pour l'étude de type comportement, expliquant les valeurs des coefficients de transition ou leur évolution. On peut le regretter dans la mesure où ces coefficients sont des paramètres déterminants dans ces modèles.

On remarque également le faible nombre de relations dites de comportement: dans les plus grands modèles, la plupart des relations sont des relations de définition, dont le seul effet est d'assurer la cohérence des phénomènes repérés par les variables, et qui en fait représentent des identités: les variables reflétant le comportement humain sont alors considérées comme exogènes au modèle ! Il faut signaler cependant la présence du "point de vue comportement" dans les problèmes (rencontrés en particulier aux Etats-Unis) concernant l'égalité devant l'enseignement et l'évaluation économique de l'enseignement en terme de rendement d'investissement.

Il semble qu'on doive souhaiter, à partir d'arguments intuitifs, la réconciliation des deux points de vue pour l'étude pertinente des problèmes de politique et de planification dans le secteur de l'enseignement; elle seule pourrait conduire à une description relativement complète du système complexe que constitue l'enseignement.

Approche micro/macro

Par approche "macro", on entend l'étude des gros agrégats alors que l'approche "micro" s'intéresse aux diverses composantes de ces agrégats; en terme d'enseignement, les effectifs d'inscrits, les dépenses publiques et privées sont des variables de type "macro"; par contre la capacité d'une institution, ses règles de recrutement sont des variables de type "micro". Il n'existe actuellement pas de modèle dans l'enseignement (type modèle d'équilibre en économie) où les variables de l'un et l'autre types coexistent et se définissent l'une par rapport à l'autre: aucun pont n'est tenté dans l'état actuel des recherches.

Taux de rendement/planification de main-d'oeuvre

Il s'agit là d'une controverse traditionnelle. Dans un cas on veut déterminer les coûts et les bénéfices de divers types d'enseignement et il faut alors calculer le taux de rendement associé à chaque cas. On cherche alors le point où les taux de rendement dans chaque branche sont égaux, en principe en actualisant les bénéfices sociaux futurs dans le long terme (mais l'éventualité de changement des structures crée des difficultés). Avec l'autre approche, on considère que ce sont les besoins en main-d'oeuvre qui doivent déterminer l'offre d'enseignement: celle-ci résulte donc d'un processus automatique et unilatéral engendré au niveau des secteurs producteurs de l'économie par les coefficients technologiques liant travail et production. A partir des besoins de main-d'oeuvre les stratégies par lesquelles le système d'enseignement doit produire les effectifs qualifiés à chaque niveau sont définies: il n'y a aucune interaction entre les deux secteurs. Il semble bien ici encore qu'une approche mixte soit nécessaire pour la réalisation de modèles adaptés aux problèmes de décision et de politique en matière d'enseignement.

Ecart entre la raison d'être des modèles et les finalités de l'enseignement

L'enquête a montré à quel point l'écart est grand entre les modèles mathématiques formels et leur utilisation effective comme aide à la décision ou instrument de planification. Il apparaît que l'intérêt est encore excessivement académique ou expérimental dans ce domaine où les expériences sont récentes, ce qui explique sans doute le scepticisme souvent rencontré chez les administrateurs. On trouve cependant de remarquables exceptions de cas où les modèles sont bien adaptés et utilisés dans la pratique; il faut pourtant souhaiter la multiplication des modèles de décision dont les objectifs seraient définis en fonction des problèmes spécifiques soulevés dans le secteur Enseignement du pays considéré.

Autres questions

On regrettera dans de nombreux modèles la non-simultanéité du système d'équations qui interdit les mécanismes de rétroaction ("feedback") et qui entraîne par conséquent une simplification abusive de la représentation causale des phénomènes. De plus, on trouve rarement la justification du niveau d'agrégation choisi pour réaliser le modèle, alors qu'il est bien connu que le "bruit de fond" perturbant la solution du modèle augmente considérablement avec sa taille: il faudrait comparer les résultats de modèles plus ou moins agrégés.

Enfin on a noté l'accent mis sur le long terme (au détriment du court terme). Certes, par sa nature même, l'enseignement possède un caractère propre au long terme, aussi bien par ses conséquences qu'au niveau de ses facteurs (la démographie par exemple). Il est indéniable pourtant que certaines décisions concernent le court terme, sans être pour autant négligeables; ce point mériterait davantage d'attention.

2. RECOMMANDATIONS POUR LES TRAVAUX FUTURS

Ces recommandations résultent des travaux d'un groupe d'experts réunis par l'OCDE le 12 juin 1969. Le "premier point" concerne l'écart déjà signalé entre la construction des modèles mathématiques formels et leur utilisation au stade de la décision ou de la planification; une des principales tâches actuelles devrait consister à travailler à réduire cet écart, et l'on peut espérer que cette enquête y contribuera.

Les modèles de "paramètres" pour les étudiants d'une part, et les modèles concernant la productivité d'autre part, qui sont des auxiliaires importants pour l'étude des besoins en ressources, mériteraient d'être exploités plus à fond. D'une façon générale, les modèles de besoins en ressources sont essentiels au niveau des gouvernements: comment arriver à des décisions optimales (ou presque optimales) sur la façon de répartir ces ressources ? Il s'agit là d'un domaine assez peu exploré. D'autre part, est-il possible de construire des modèles généraux et assez souples pour permettre de calculer rapidement les dépenses nécessitées par les prévisions alternatives d'élèves ? Citons également le problème de la révision, chaque année, des objectifs d'un modèle pour atteindre les finalités prévues dans le long terme. On note enfin la nécessité d'une étude critique des modèles d'allocation utilisant la programmation linéaire. A propos des modèles établissant des liens avec des secteurs autres que l'enseignement, signalons l'intérêt de l'étude quant à son rapport avec l'emploi et le problème de la mobilité de l'emploi.

A propos des modèles de prévision, et malgré leurs mauvais résultats dans de nombreux cas, il faut reconnaître leur utilité et souhaiter, en priorité, leur amélioration. Pourquoi ces modèles ne donnent-ils pas satisfaction ? Il faudrait ici étudier, dans le détail, les méthodes d'estimation des coefficients sur lesquels reposent les prévisions: d'autre part, il semble que les modèles de projection sont trop rigides lorsqu'ils considèrent comme fixée la structure du système. Enfin, on insistera sur la nécessité d'étudier la sensibilité des estimations aux variations données aux diverses variables de décision et hypothèses du modèle, en même temps qu'on déterminera comment les variables instrumentales sont introduites et manipulées en vue des différentes finalités de l'enseignement.

3. UNE PROPOSITION

Si les modèles sont parfois bien adaptés aux problèmes de l'enseignement du pays où ils ont été construits, on peut aussi sans doute beaucoup attendre de leur transplantation dans un autre pays. Plutôt que de renouveler à grands frais un effort déjà fourni, n'est-il pas imaginable d'utiliser une technologie déjà mise à l'épreuve ? Pour qu'une telle opération soit possible, il est nécessaire que la structure du modèle soit d'une nature assez générale, non assujettie aux caractéristiques particulières d'un pays. On imagine ainsi la naissance d'une "banque de modèles", continuellement mise à jour, tant pour l'aspect technique que pour les entrées et sorties des modèles; les autorités officielles, principales bénéficiaires, y coopéreraient d'autant plus volontiers qu'elles seraient aisément convaincues de l'utilité d'une telle opération.

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